Pest Management Alliance Project Final Report

Multi-Disciplinary Approach to Methyl Bromide Replacement in Strawberries Using Non-Chemical Alternatives

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PRINCIPAL INVESTIGATORS
Frank Westerlund, Christopher Winterbottom

CONTRACTOR
California Strawberry Commission

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Acknowledgments

The California Strawberry Commission acknowledges the following persons for assisting in the realization of this Pest Management Alliance program:

Participants:

California Strawberry Commission
P.O. Box 269
Watsonville, CA 95077

Frank Westerlund (Currently on Leave)	(831)724-1301	
Christopher Winterbottom (Currently with Sunrise Growers, Inc.)	(831)786-0109	cwinterb@sunrisegrowers.com

California Certified Organic Farmers

Brian McElroy	(831)423-2263	

US Department of Agriculture

Frank Martin	(831)755-2873	fmartin@asrr.arsusda.gov
Carolee Bull	(831)755-2889	ctbull@aol.com
Husein Ajwa (Currently with UC Davis Extension Service)	(559)453-3105	hajwa@ucdavis.edu

University of California

John Duniway	(530)752-0324	jmduniway@ucdavis.edu
Colin Carter	(530)752-6054	colin@primal.ucdavis.edu
Rachel Goodhue	(530)754-7812	goodhue@primal.ucdavis.edu
Greg Browne	(530)754-9351	gtbrowne@ucdavis.edu

UC Cooperative Extension

Richard Molinar	(559)456-7555	rhmolinar@ucdavis.edu
Sujaya Udayagiri	(831)763-8026	
Steven Fennimore	(831)755-2896	safennimore@ucdavis.edu
Steven Koike	(831)759-7350	stkoike@ucdavis.edu
Krishna Subbarao	(831)755-2890	

Coastal Berry Company

Stuart Yamamoto	(831)728-9611	stuart@coastalberry.com

Misha Berry Farms

Paul Kohatsu	(831)759-2273	ckohatsu@mishaberryfarms.com

Shinta Kawahara

Rod Koda	(831)722-4919	gwenkoda@aol.com

Ramos Farms
Miguel Ramos (831)761-9941

Pesticide Control Advisors:

Steve Nelson	Plant Sciences Inc.
Randy Malone	Ag Rx
William Harrison	Kurt Produce, Inc.
Gary Omori	
Lawrence London	

Technical Assistance:
Stan Van Vleck Kahn, Soares & Conway

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Executive Summary

California is first in strawberry production in the United States, producing 80% of fresh market strawberries. Strawberries are grown on approximately 25,000 acres per year in California, and have an average annual value of approximately $734 million. The continued economic success of the strawberry industry in California will continue to rest, in part, on the industry's ability to develop a pest management program that balances cultural and biological control practices with chemical treatment.

For many years the strawberry industry has relied on both chemical treatments and cultural practices to diminish the impact of soil-borne diseases, insects, and weeds on the yield and quality of the fruit. In recent decades, the most important treatment has been methyl bromide, a broad-spectrum soil fumigant, applied in combination with chloropicrin. Preplant applications control most agronomically important diseases, prevent weed germination, and control arthropods present in the soil.

Methyl bromide has been identified, however, as having the potential to deplete the Earth's ozone layer, and for this reason its use is being phased out. Importation and domestic production of methyl bromide are to cease by the year 2005. At present no broad-spectrum, drop-in replacement for methyl bromide is yet available to the strawberry industry.

Recognizing this problem, the California Strawberry Commission conducted a statewide, multi-faceted program during 1997-1999 (Pest Management Alliance Contract No. 97-0259 in addition to grants from USDA, US EPA, UC SAREP, and CSC research money) to enable California's strawberry industry to rapidly identify and implement alternatives in managing soil-borne diseases. The program successfully demonstrated promising, technically feasible alternatives to the use of methyl bromide within the limitations of the studies. However, the economic viability of the tested alternatives to methyl bromide remains to be demonstrated. No tested alternative is an exact replacement for methyl bromide and use of each potential alternative has impacts throughout the entire economics of strawberry culture in California.

Developing a sound, multi-faceted, reduced-risk approach to integrated pest management for the long term is critical. Such an IPM program would provide viable bio-control and cultural practices, as well as chemical tools to provide replacements for the wide array of disease, insect, nematode, and weed control that are currently obtained through the use of methyl bromide. The focus of this Pest Management Alliance (PMA) Work Plan is to identify, demonstrate and implement non-chemical methods, such as cultural and biological control methods that could be implemented in an integrated pest management approach as reduced-risk replacements for methyl bromide.

Ten areas of non-chemical pest control were investigated.

1. Organic Amendments with Beneficial Microorganisms
2. Crop Rotation
3. Organic Composting (High Nitrogen Composts)
4. Tarps and Films (Colored Tarps and High-Barrier Film)
5. Solarization
6. Non-Chemical Weed Control
7. Plant-Back Timing With Non-Chemical Techniques
8. Cultivar Tolerance to Non-Chemical Techniques
9. Coordination and Demonstration with Chemical Alternatives Research
10. Economic Assessment of Non-Chemical Alternatives.

In conclusion, some promising but preliminary results were obtained in the studies. The work with beneficial microorganisms, crop rotation, organic composting and solarization showed some promise, but additional work is required in strawberry culture. Colored tarps showed that weeds can be controlled best with black and green colored mulches. Ozone had poor efficacy in weed control. And cultivar testing for resistance to Verticilium and Phytophthora were mixed. While the cultivars tested showed poor resistance to Verticilium, some were fairly resistant to Phytophthora giving hope to future breeding programs that resistant plants can be developed.

Research results were discussed at six well attended Field Days in 2001, a total of 740 growers attending.

Introduction

1. Organic Amendment with Beneficial Microorganisms

The task focuses on two programs using beneficial microorganisms as alternates to the use of methyl bromide. Fumigation has been shown to change the make up of microorganisms in the soil dramatically, a transformation that apparently has direct benefit on strawberry growth and yield. Certain microorganisms have been shown to improve root health, growth, and yield in strawberry plants in either the absence of soil fumigation (organically grown conditions) or when using less effective fumigation materials. Fumigation not only removes pathogenic organisms in the soil but also enhances the availability of beneficial organisms. Mimicking these effects, through the use of beneficial microorganisms is the goal of this task. First, microorganisms found to promote root growth in strawberries will be isolated from strawberry roots and used as soil amendments. Second, commercially available beneficial organisms will be used as soil amendments. These amendments will be characterized for their effectiveness against the spectrum of pests currently controlled by methyl bromide or, in the case of organically certified fields, their effectiveness against commercially important soil-borne pests. The ultimate effects on yield and quality will be assessed. The effective amendments will be placed into demonstrations for the industry.

Research has shown that root colonization by specific bacteria or fungi can give general increases in plant growth, yield, and/or measurable control of known root pathogens (Cook, 1993; Weller, 1988). Bacteria with these activities on plants are usually competent root colonizers (Kluepfel, 1993). Strawberry plants in fumigated soils consistently have much higher root length densities and fewer dark roots than plants in nonfumigated soils. Relative to nonfumigated soils, total numbers of soil-borne fungi are usually low for several months following fumigation. Species of *Cylindrocarpon, Pythium,* and *Rhizoctonia*, which are typically damaging to strawberry roots, are isolated significantly less often from roots in fumigated soils than in nonfumigated soils. Populations of fluorescent pseudomonads in soil, however, increase quickly following fumigation to be 10-1000 fold higher than in nonfumigated soils 10-9 months after fumigation. Predominant isolates of fluorescent pseudomonads from rhizosphere have been tested for effects on strawberry growth in natural field soil in the greenhouse. Effects of individual isolates were variable ranging from beneficial to deleterious (Wing, 1994; Yuen, et al, 1991). The most predominant and beneficial rhizobacteria tested were *Pseudomonas fluorescens, P. putida and P. chlororaphis*. It is suggested that reductions in deleterious fungi and increases in beneficial fluorescent pseudomonads contribute to the enhanced growth response of strawberry.

The goal was to find and effectively deploy microorganisms to improve root health, growth and yield without soil fumigation or with less than optimum soil fumigation treatments. Assessments will be made by both the fruit and plant production industries as well as by representatives from organic farming. Scaled up demonstrations of the optimal treatment regimes will be performed.

Field trials will be established at the Monterey Bay Academy near Watsonville on land leased by the CSC and farmed using normal practices for strawberry production in the area on 2-row beds. Isolates from strawberry plants and commercially available organic-compatible vesicular arbuscular mycorrhizal innoculants (AM) that performed well in recent trials will be applied in small replicated plots in Watsonville, Oxnard, or Santa Maria. Appropriate standard fumigated and nonfumigated controls will be included, and growth, berry yield, and rooting will be measured along with an assessment on the relative effectiveness against the spectrum of soil-borne pests that methyl bromide is currently used to control.

Objectives. The following are the objectives of our proposed research on beneficial microorganisms. A multi-year program will be needed to fully assess the success of the research and ensure that the industry is willing and able to adopt the most effect organic amendments. The following summary, for PMA Work Plan purposes, focuses on the proposed tasks of the first year of the program, beginning June 15, 2000. The primary objectives are identified as follows:

1. Evaluate the effects of bacteria in laboratory and greenhouse screens to identify potential bacteria for field trials. (Much of this research was performed during the previous 12 months).

2. Isolate three to five pseudomonads with sufficient activity in laboratory and greenhouse experiments to warrant field testing. Isolates giving plant growth responses within 5-6 weeks, or improved root health will be retained for further testing.

3. Repeat inoculations of seedlings transplanted into natural and sterilized soil.

4. Evaluate the effects of promising bacteria in field trials for improved root health, growth and berry yield without soil fumigation or with less than optimum soil fumigation treatments.

5. Evaluate the effects of promising bacteria in a field with 5 year history of non-fumigation and history of rotation with broccoli.

6. Evaluate seven commercially available AM Innoculants on plant yield with different cultivars.

7. Expansion to demonstration plots for adoption by industry. Once optimal organic amendments are identified and proposed use patterns are determined for integration into organic and conventional pest management programs, regional demonstrations, comparing to commercial standards, will be performed.

2. Crop Rotation

The effects of crop rotation on the suppression of soil-borne diseases and maintaining crop yields have been recognized, but the use of rotations as an agronomic tool has largely been neglected by growers because of the availability and cost-effectiveness of chemical fertilizers, pesticides, and soil fumigants. Crop rotations generally reduce populations of pathogens because pathogens of one crop are unlikely to infect and multiply on an unrelated crop. Another mechanism by which crop rotations suppress soil-borne diseases may include changes in microbial interactions or changes in soil physical factors. A broccoli crop grown prior to a strawberry crop has the potential to mitigate certain soil-borne diseases in strawberry cropping systems in coastal valleys. Subbarao and Hubbard (1996) and Subbarao (unpublished) have demonstrated that rotations with broccoli nearly eliminate propagules of *V. dahliae*.

Three experiments on a broccoli-strawberry rotation on nonfumigated soils have recently been completed (Duniway, et al., 1997). At Davis, California, where *V. dahliae* is absent, one year of fallow or one year of broccoli production did not increase subsequent strawberry yields over that obtained with continuous production strawberry. However, at a Watsonville site with high populations of *V. dahliae* present, a one-year rotation with broccoli increased subsequent strawberry yields by 24% and one year of rye increased yield 18%, relative to continuous strawberry, all on nonfumigated soil. Fumigation with methyl bromide and chloropicrin at the same experimental sites increased strawberry yields 46-69%.

Goal. To study the applicability and efficacy of strawberry crop rotation with broccoli, lettuce, and brussel sprouts in soil with a history of fumigation, as well as in organic-certified fields. Effective procedures will be demonstrated and compared to current practices so that optimal adoption by the conventional and organic growers can be realized.

Objectives. A multi-year program will be needed to fully assess the success of the research, however, for PMA Work Plan purposes, the proposed tasks and budget are identified only for the one year period beginning, June 15, 2000, with an interim report summarizing findings to date at the end of the PMA funding period. The primary objectives are identified as follows:

1. Evaluate the effects of broccoli, lettuce, and brussel sprouts rotation in plots with history of fumigation and history of rotation with broccoli and lettuce.

2. Evaluate the effects of broccoli, brussel sprouts, and lettuce rotation in organic plots.

3. Evaluate the effects of broccoli crop rotation in conjunction with beneficial microorganisms in field with 5-year non-fumigation history (see Organic Amendments - Beneficial Organisms above).

3. Organic Composting

There is evidence that some composts and other organic amendments of soil can suppress soil-borne plant diseases and generally benefit plant growth (Cheney, et al. 1992, Grebus, et al. 1994, Huber, 1991). There are at least two published trials or organic composts added to soil for strawberry production in California. One describes a conversion from standard production practices with soil fumigation to organic production methods without fumigation (Gliessman, et al. 1996). Unfortunately, a comparison to continuing fumigation and conventional production practices was not part of this study. The second study included conventional production practices with methyl bromide and some of its chemical alternatives, as well as non-treated, conventionally managed soil (Sances & Ingham, 1997). Broccoli residue, spent mushroom compost, alone or in combination, did not increase yield significantly and these treatments yielded 40-45% less than the standard methyl bromide/chloropicrin fumigation treatment.

While it is unlikely that organic soil amendments can fully duplicate the beneficial effects of soil fumigation, additional research is needed to determine if organic amendments to soil can be applied with consistent benefit in strawberry production, both in the short- and long-term. Various organic materials such as manures, sewage sludge, food processing wastes, and composts have been researched for their potential disease suppressive effects when incorporated into soils (Chaney, et al. 1992; Davis, et al. 1996; Gliessman, et al. 1996; Grebus, et al 1994; Huber, 1991; Jordan, et al. 1972; Sances and Ingham, 1997; Tjamos, 1989). More specifically others have found additions of high-nitrogen organic amendments to reduce populations of *Verticillium dahliae* in soil and the incidence of Verticillium wilt in potato (Conn and Lazarovits, 1999; Lazarovits, et al. 1997).

Goal. To study the effects of high nitrogen organic amendments to strawberry growth and yield and effectiveness against soil-borne pests currently controlled by methyl bromide or of economic importance to production of organically grown strawberries.

Objective. A multi-year program will be needed to fully assess the success of the research, however, for PMA Work Plan purposes, the proposed tasks focus on the first year, beginning June 15, 2000, with an interim report summarizing findings to date at the end of the PMA funding period. The primary objective is identified as follows:

To evaluate the activity and phytotoxicity of high nitrogen soil amendments for suppression of *Verticillium* wilt in Camarosa strawberries.

4. Colored Tarps

The effectiveness of clear tarp for solar fumigation of the weed seedbank has long been established (Hartz et al. 1993). The use of polyethylene tarps or mulches has been a standard practice in strawberry production. Covering the planting bed with plastic mulch helps regulate plant growth and fruit production; it also limits fruit contact with soil and irrigation water, which reduces decay problems. Clear mulches provide no weed control but warm the soil and advance the strawberry harvest date, while black mulches prevent weed growth, but substantially delay harvest and may potentially cause fruit burn. Black mulch is sometimes used by organic growers for weed control. Tarps are now available in many colors, each of which filters light and effects fruit production differently. For example, blue light inhibits the germination of the seed of many weed species, therefore, the blue tarp appears promising.

Soil solarization in coastal areas of California is generally less effective than in interior regions. Which raises the question, what can be done in coastal areas to increase soil temperatures above the weed seed thermal death point? Soil solarization inside greenhouses is quite effective since the greenhouse acts to trap heat better than field solarization (Elmore et al. 1997). Therefore, it may be possible to use two layers of plastic tarp to create a dead air space and increase soil temperatures compared to the use of a single layer of clear plastic.

Goal. To compare the influence of the color of plastic mulch on weed control, effectiveness against other soil-borne pests, and berry yield and quality. Mulch colors to be tested include blue, brown, green, red, and yellow, as well as the standard clear and black tarps. Effectiveness under conventional and organic growing conditions will be assessed. If available for comparison, high barrier films will also be used to assess soil pest management effectiveness.

Objective. Evaluate the control of weed and adverse effects of colored tarps on strawberry production and yield.

5. Solarization

Soil solarization is a method of reducing soil pests by using the energy of the sun. Plastic tarp is used to retain solar radiant heat in the soil so that a soil temperature is maintained for a sufficient duration of time to be detrimental to soil-borne pests. The strawberry growing region in California that is best suited for this cultural control method is the San Joaquin Valley, where environmental conditions enable sufficient heat through solarization to occur. Although killing of pathogens by heating is involved, microbiological mechanisms are also involved (Gamliel, and Katan, J. 1991).

Preliminary work has been done in California by Pullman (unpublished), Elmore (unpublished), and Hartz (1993). Pullman primarily studied soil solarization parameters in the various climactic regions of California. Hartz, in a two year study at a single location in southern California, studied the effectiveness of solarization for strawberry production, and Elmore investigated weed control in strawberry at three locations on the central coast. Due to environmental factors - mainly amount and duration of sunlight - Pullman concluded that soil solarization alone as a means of pre-plant soil preparation to control soil-borne pests would only be effective in the inland valleys and southern coast of California.

Soil solarization for control of soil-borne pests is dependent upon, but not limited to, the following parameters: type of plastic film, configuration of plastic film, soil type, soil preparation, soil moisture, soil temperature, length of day, intensity of sunlight, and presence or absence of certain crop residues. Data from a *single* soil solarization study done in southern California resulted in strawberry fruit production from plots receiving pre-plant soil fumigation with methyl bromide/chloropicrin yielding an average of 33% more than plots that were solarized. Hence a reduction in yield is expected from use of solarization alone as a means of controlling soil-borne pests. Input costs are expected to increase due to an increase in the use of pesticides required to control fungal, weed, nematode, arthropod, insect and arachnid pests. Assuming production costs do not change significantly, reduced revenue is expected if a concomitant increase in return to the farmer on reduced output is not realized.

Goal. To better determine the feasibility of solarization for strawberry production, we propose investigating the applicability and efficacy of soil solarization as a means of pre-plant soil preparation for strawberry production, initially in the San Joaquin Valley followed by modified techniques that may be appropriate for the cooler growing regions of the state.

A field trial will be established on a commercial strawberry production farm in California. All treatments will be farmer applied in large scale blocks. Yield and fruit quality data will be collected from three twenty-plant plots within each treatment. Observations will be made of the effectiveness against weeds and other soil born pests currently controlled by methyl bromide or economically important to producers of organically grown strawberries.

Objectives. The following are the objectives of our proposed research on solarization:

1. Evaluate the effects of solarization on the plant growth, yield and quality in the San Joaquin Valley.

2. Evaluate the effects of solarization on soil-borne pests currently controlled by methyl bromide such as weeds, insects, and diseases.

3. Evaluate the effects of solarization in enhancing soil populations of saprophytic (non-pathogenic) microorganisms in relation to strawberry yield and root health.

4. Identify sites and design modified procedures for solarization in coastal growing regions.

6. Non-Chemical Weed Control

With a few exceptions, methyl bromide provides excellent weed control in strawberries (Agamalian et al. 1993). However, as the methyl bromide phase-out approaches the 50% reduction level in 2001, there is renewed interest in weed control with methyl bromide alternatives. There are a number of potential methyl bromide alternatives for conventional strawberries (Trout and Ajwa 1999). However, the list of non-chemical alternatives is very limited. Therefore, there is a great need for further research into non-chemical weed control alternatives for strawberries.

The use of broccoli residues as a biofumigant for the control of soil-borne diseases has been demonstrated (Subbarao et al. 1998). Therefore, we asked the question as to whether broccoli residues combined with soil solarization could be used to enhance the weed control efficacy in strawberries, particularly if coupled with other non-chemical treatments such as soil solarization on the cool central coast.

Corn gluten meal (CGM) has been reported to have herbicidal properties (Christians 1994). However, previous attempts to verify the weed control activities of CGM in our hands have been unsuccessful (Fennimore et al. 2000).

Objectives. To ensure that all non-chemical pest control methods evaluated within this PMA Work Plan have been accessed for their relative effectiveness in controlling weed germination. Also, the effectiveness of corn gluten meal and broccoli residues in controlling weed germination will be evaluated. The evaluations will be performed relative to both conventional and organic standards. The assessments will be designed for communications on demonstrations of these non-chemical techniques and their scope of efficacy compared to these industries' standards.

Weed scientist attached to our team, both from the UCCE and CCOF, will be utilized to perform these assessments so a comprehensive comparative evaluation of weed control by these non-chemical pest management techniques can be generated. Tasks:

1. All the above projects will have their effectiveness on controlling weed germination evaluated. These evaluation will include:

    - Organic Amendments with Beneficial Microorganisms
    - Crop Rotation

- Organic Composting with High Nitrogen Composts
- Color Tarps and Films
- Solarization

2. The results from the above evaluations will be integrated into the development of demonstration plots to evaluate integrated uses of non-chemical alternatives and techniques.

3. Evaluation of corn gluten meal and broccoli residues will be performed as non-chemical alternates. Trials will be established that evaluate these substances alone and with the following non-chemical control methods (as determined be previous experimentation to be complementary to the use of corn gluten meal and/or broccoli residues:

- Color tarps
- Organic amendments (beneficial organisms)
- Solarization

7. Pest Management Timing – Plant Back Timing

The PMA team must assess the optimization timing for coordinating different alternate pest management techniques. Research will include an assessment of the appropriate plant-back timing following the use of the alternate methods and include these results in the demonstrations for the industry so that these plant-back restrictions, if any, can be compared to the plant-back restrictions with more traditional, chemical-based treatments.

With the impending loss of methyl bromide, the strawberry industry has worked toward developing an integrated pest management approach to address the broad spectrum control that was provided by methyl bromide. As new practices are developed, it must be determined how they fit into the strawberry pest management system. A common problem is determining the plant back timing. Plant back time, for the PMA Work Plan purposes, is defined as the amount of time (days) needed from soil bed treatment to the time strawberry transplants may be safely planted in the bed. Too short a plant back time could result in plant death, or stunted chlorotic plants that do not perform well. Proper plant back time is a key to establishing a vigorous stand of strawberry plants. Whether soil treatment is a traditional chemical treatment or an alternative treatment, such as a high nitrogen soil amendment, plant back timing is an important facet in the integrated pest management approach.

Objectives. To determine phytotoxicity of the non-chemical treatments being performed in this PMA proposal, a bioassay system (typically radishes or another high germination, quick growth plant), is planted at 3 day intervals. The bioassays use root vegetables that sprout quickly and thrive under the same soil conditions that are optimum for strawberries, and conversely, are sensitive showing phytotoxic effects to soil conditions that are not optimum to strawberries. The tasks will be the following:

1. To determine the plant back time in alternative soil amendment treatments conducted at the Monterey Bay Academy. Plant back trails will also be performed if other PMA non-chemical techniques where plant-back periods are anticipated are performed at locations other than the Monterey Bay Academy.

2. At onset of soil amendment treatment, radishes will be planted at 3 day intervals. Trials to be included are organic amendments and organic compost trials. Solarization, non-chemical weed controls, and tarp experimentation may also be relevant to these bioassays.

3. Monitor radishes for vigor and phytotoxic effects at regular intervals.

4. Analyze results and determine plant back timing for soil amendment treatments.

5. Participate in field day demonstrations and use results to design optimal large scale demonstrations of non-chemical techniques to the industry.

8. Cultivar Tolerance to Non-Chemical Techniques

Phytophthora spp. can infect the roots, crown, and fruit of strawberry plants and are serious soil-borne pathogens. In California, most of the damage results from root and crown infections, which cause plant stunting and collapse. Phytophthora root and crown rots are favored by cool to moderate temperatures and extended by frequent periods of water saturation in or on soil. The disease-causing potential of these pathogens is an annual concern for strawberry nurserymen, growers, and breeders.

Although several strawberry cultivars used in the eastern and northwestern United States have been bred with resistance to most races of *P. fragariae*, the annual methyl bromide fumigation system for California strawberries has historically made such resistance less important for California growers. Without effective fumigation, however, management of red stele disease (as well as Phytophthora crown rot and Verticillium wilt, among other soilborne diseases) will become more difficult, relying to a greater extent on cultural practices, fungicides, and genetic resistance.

Experiments completed at Monterey Bay Academy (MBA) and Wolfskill (WEO) during 1997/98 tested several methods for field screening resistance to *P. cactorum* and *P. citricola* in some new and standard California cultivars. The first-year results demonstrated that field screening for resistance to these pathogens is feasible and revealed large differences in resistance to crown rot among the cultivars tested. Although all cultivars exhibited early season stunting after inoculation with *Phytophthora*, only Diamante and Pajaro suffered high incidence of plant collapse and severe fruit yield loss. Expanded evaluations of resistance underway at MBA and include Aromas, Camarosa, Diamante, Gaviota, Pacific, Pajaro, and Parker. Complimentary screening experiments are running at WEO with the same cultivars from low and high elevation backgrounds.

Goal. This task will use the cultivar screening techniques developed for evaluation of resistance to *Phytophthora* (described above) to assess the differences between cultivars in their responses to the non-chemical pest management programs proposed in this PMA Work Plan. Assessments will be performed of cultivar sensitivities to organic amendments, organic composts, crop rotation techniques, and use of color tarps.

Objectives. Field experiments are proposed at Monterey Bay Academy to screen the effect that selected non-chemical treatments have on resistance to *P. cactorum* and *P. citricola*. Comparisons of commercially available cultivars will be made. Likely cultivars to be used are Aromas, Camarosa, Diamante, Gaviota, Pacific, Pajaro, and Parker. These studies will be coordinated with the other tasks described above in our Work Plan. In particular, the following non-chemical treatments will be assessed for their differential impacts on the various commercially available cultivars:

- Organic Amendments with Beneficial Organisms.
- Organic High-Nitrogen Composts
- Crop Rotations
- Color Tarps

The *Phytophthora* field-based screening assay is a means by which a reasonably large number of cultivars can be assessed with in a short period of time with a limited use of acreage.

9. Coordination and Demonstration with Chemical Alternatives Research

Our goal is the early adoption of alternate non-chemical application techniques by California's strawberry industry through the use of comparative demonstration trials. The purpose will be to effectively demonstrate the appropriate, economically feasible means by which these non-chemical pest management techniques can be integrated into the pest control systems used in commercial production of strawberries in California, both conventional and organic.

Objectives. Regional sites will be designed to demonstrate these reduced risk, non-chemical alternative control methods in direct, side-by-side trials with the current industry standards. The industry standards will be chemical techniques, including fumigations with methyl bromide, for growers that use conventional pest management practices. For growers that utilize techniques that follow organically grown certification, the common pest management practices used by these growers will be used as the standards for comparison. In 2000, these master comparative trials are initially scheduled for both the Oxnard and Watsonville growing regions. They will be continued and expanded in future growing seasons.

10. Economic Assessment of Non-Chemical Alternatives

In order for these non-chemical alternatives to methyl bromide treatment to become adopted by the industry, the growers need to understand the economic consequences of changing the pest management practice. All of the research listed above, including the side by side comparison of these non-chemical techniques to existing commercial pest management programs, will be assessed. Experts in pest management costs for strawberries will develop economic assessment of our non-chemical techniques and compare these assessments to commonly practiced pest management programs and the anticipated economics when the industry's central chemical tool, methyl bromide, is prohibited.

Goal. Develop the economic assessment of the non-chemical alternatives developed under this PMA Work Plan, utilizing the optimal conditions for the techniques as determined with our proposed field-based experimentation.

Objectives. Experts in pest management costs for strawberries from the University of California's Department of Agricultural Economics will be utilized to develop an economic assessment of our non-chemical techniques, based on the results obtained through this PMA program. These assessments will compare the economics of our non-chemical techniques to existing pest management practices commonly used by the industry such as chemical fumigation. Comparisons will also be made to the economics of pest management anticipated when the industry's central chemical tool, methyl bromide, is eliminated. These assessments will be made available to the industry through our field demonstrations and written communications. Assessments relevant to both conventional and CCOF members will be developed.

Results

1. Amendments with Beneficial Microorganisms (Duniway and Bull)

John Duniway

Strawberry plants in fumigated soils consistently have much higher root length densities and fewer dark roots than plants in nonfumigated soils. Species of *Cylindrocarpon, Pythium,* and *Rhizoctonia*, which are typically damaging to strawberry roots, are isolated significantly less often from roots in fumigated soils than in non fumigated soils. Populations of fluorescent pseudomonads in soil, however, increase quickly following fumigation. Predominant isolates of fluorescent pseudomonads from strawberry rhizospheres were tested for beneficial effects on strawberry growth yield in the greenhouse and field. Research in other crops has shown that root colonization by specific bacteria or fungi can give general increases in plant growth, yield, and/or measurable control of known root pathogens.

Individual bacteria were first screened for antibiosis to *Pythium*, *Rhizoctonia*, and *Cylindrocarpon* isolates found to be damaging to strawberry roots in nonfumigated soil, and to the known pathogens *Verticillium dahliae, Phytophthora cactorum*, and *Colletotrichum acutatum*. The same bacteria, as well as some fungi, were also used to root-dip inoculate clean, 10-week-old Selva and/or Aromas seedlings (5-7 replicates) as they were transplanted into natural field soil (collected where strawberry was grown without fumigation) mixed with a potting mix. Isolates that increased plant growth within 5-6 weeks, or that improved root health in the greenhouse, were retained for further testing. Since we had many isolates, priority was given to those isolates with the largest and most significant effects of strawberry growth, and second priority to isolates improving root health and having antibiosis to one or more of the fungi tested above. Further testing consisted of repeated inoculations of seedlings transplanted into a second natural soil and sterilized soil.

Individual bacteria and fungi selected by the methods above were used to inoculate strawberry plants in replicated field experiments. These experiments were done at the Monterey Bay Academy (MBA) near Watsonville. Three bed fumigation treatments were applied, i.e., a standard rate of methyl bromide with chloropicrin (MBC), a low rate of chloropicrin (200 lb/a), and not fumigated. Bare-root Selva and Aromas plants were obtained from a high elevation nursery. Roots and crowns were inoculated by dipping in concentrated suspensions of bacteria or spores at transplanting, and in some cases, plants were reinoculated periodically as they grew (i.e., to mimic delivery of microbes by drip irrigation systems).

The effects of the soil fumigation and bacterial treatments on strawberry yields in 2000 and 2001 are shown in Figures 1 and 2, respectively. Although soil fumigation had large effects, none of the inoculation treatments increased plant size or yield in MBC-treated soil, and some actually decreased berry yield. In nontreated soil, inoculation effects on yield were not significant, although some of the bacteria reduced the final incidence of Verticillium wilt significantly. In contrast, on soil treated with a low rate of chloropicrin, isolates P1 and P3 increased growth and yield significantly in 2000 and isolate 4 did so in 2001. It appears that most of the bacterial inoculations in MBC-treated soil may reduce yield somewhat while many of the same inoculation treatments may increase yield significantly in soil treated with a moderate rate of chloropicrin. The main aspects of these experiments are being repeated in 2001-01 with minor modifications and additional isolates, some of which are more active in the greenhouse than isolates tested before. While more long-term research is needed, inoculation of transplants with growth-promoting bacteria and/or biological control organisms may be beneficial and feasible. It may also be possible to manipulate soil conditions by cultural or other methods (e.g. low rates of fumigation) to enhance the activity of beneficial microorganisms.

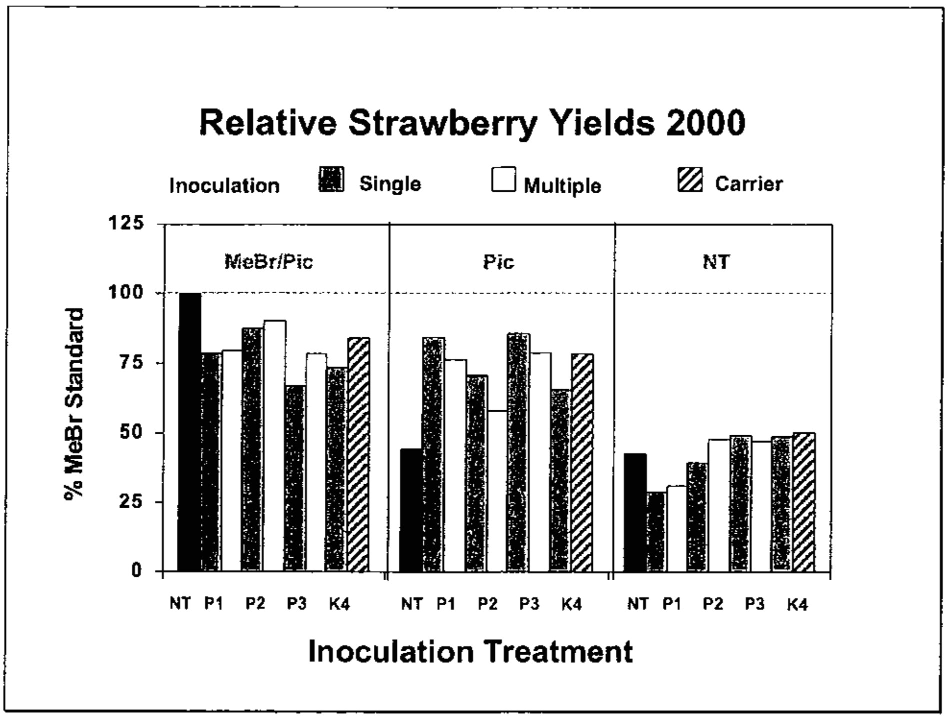

Figure 1. Effect of soil fumigation and inoculations of strawberry plants with various bacteria on yield of fresh market berries in 2000. Soil was fumigated with methyl bromide and chloropicrin (MeBr/Pic), chloropicrin alone (Pic), or not treated (NT). Plants were inoculated with individual bacterial isolates P1, P2, P3, K4, or were not treated (NT). Plants were either inoculated once at transplanting (left bar for each isolate) or were also reinoculated periodically during plant growth (right bar). Yields are give relative to that obtained without inoculation in standard methyl bromide/chloropicrin fumigated soil.

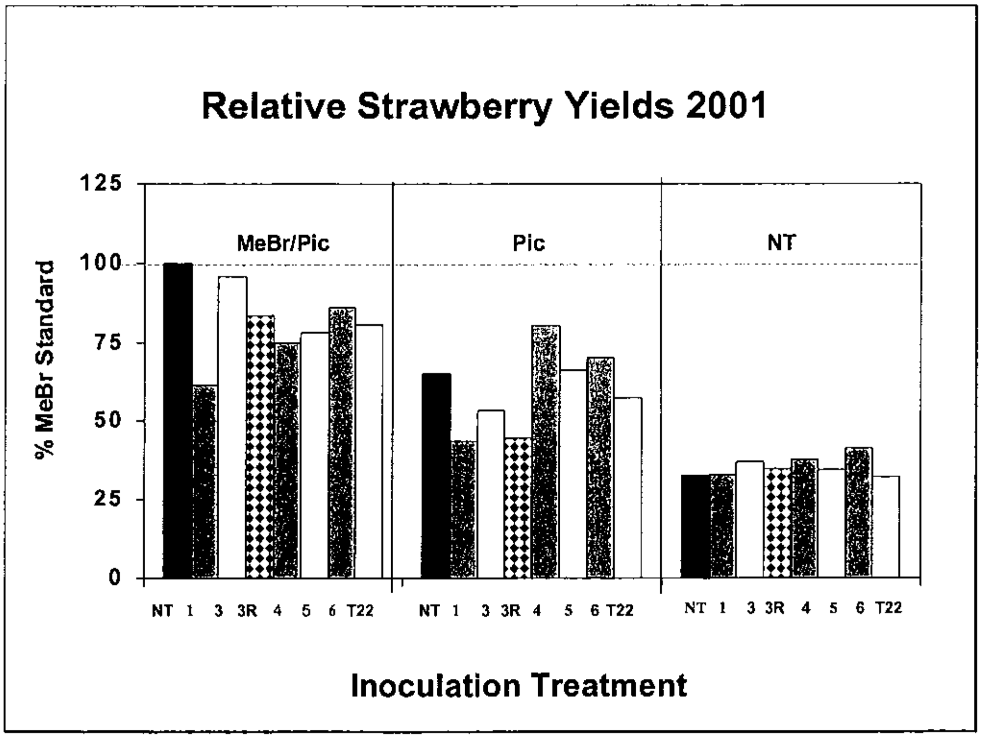

Figure 2. Effect of soil fumigation and inoculations of strawberry plants with various bacteria and a fungus on yield of fresh market berries in 2001. Soil was fumigated with methyl bromide and chloropicrin (MeBr/Pic), chloropicrin alone (Pic), or not treated (NT). Plants were inoculated with individual bacterial isolates 1, 3, 4, 5, 6, the fungus *Trichoderma harzianum* strain T-22, or were not treated (NT). Plants were either inoculated once with isolate #3 at transplanting (#3) or were also reinoculated periodically during plant growth (#3R). Yields are given relative to that obtained without inoculation in standard methyl bromide/chloropicrin fumigated soil.

Carolee Bull (Work also supported by CDPR and USDA)

None of the mycorrhizal innoculants tested (Table 1) had an influence on the yield of strawberries in organic or conventional production fields (Tables 2, 3). Colonization of strawberry roots was not influenced by inoculation (Table 2). Likewise, yields of uninoculated plants were not different than the yields of plants inoculated with any of the commercial inoculants. These data indicate that the commercially available inoculants tested do not influence yield in certified organic production fields nor do the commercially available inoculants tested influence yields in conventional production fields.

Table 1. Commercial mycorrhizal products used in these experiments.

Product	Manufacturer
Ascend PA	BioScientific, Inc.
BioVam	EcoLife, Corp.
Endomycorrhizal Inoculant	Bio/Organics, Inc.
EndoNet	Reforestation Technologies International
Vaminoc	Microbio, Ltd. Royston Herts, UK
Endos	AgBio, Inc.
Strawberry Saver	Plant Health Care, Inc.

Mention of trade names does not constitute an endorsement by the USDA or CA-DPR.

Table 2. Effect of commercial inoculants on colonization of strawberry (cv. Aromas, March 2001).

Treatment	Colonization of strawberry roots (% colonized)
1[X]	52
2	54
3	56
4	44
5	51
6	51
7	50

[X]Treatment 1 is the uninoculated control; Treatments 2-7 were commercially available inoculants listed in Table 1.
[Y]Significant differences were not detected among treatments and any of the locations.

Table 3. Yield of strawberries inoculated with commercially available mycorrhizal inoculants and grown in organic or conventional production fields.

Treatment	Market Yield (K gm/plot ± standard error) 2000 C	2001 C
1[X]	18.7 ± 1.2	13.1 ± 2.0
2	19.1 ± 1.2	11.0 ± 2.0
3	19.0 ± 1.2	14.9 ± 2.0
4	19.3 ± 1.2	11.1 ± 2.0
5	18.4 ±1.2	NT[Z]
6	19.1 ± 1.2	13.3 ± 2.0
7	20.0 ± 1.2	11.5 ± 2.0
8	NT	11.6 ± 2.0

[X]Treatment 1 is the uninoculated control; Treatments 2-8 were commercially available inoculants listed in Table 1.
[Y]Significant differences were not detected among treatments at the (P=0.05) according to Tukey-Kramer HSD.
[Z]NT=not tested

2. Crop Rotation (Martin)

Verticillium wilt is the most important soilborne pathogen of strawberries because of the premature plant death it causes. Estimates of crop losses vary but range between 30-50% in the absence of soil fumigation. Currently available commercial strawberry cultivars are all highly susceptible to Verticillium wilt. The disease has been managed effectively by pre-plant soil fumigation with methyl bromide and chloropicrin. The imminent loss of methyl bromide, however, leaves few alternatives for effective management of Verticillium wilt and other soilborne diseases in strawberries. The disease is caused by the fungus, *Verticillium dahliae*, which is widely distributed in the agricultural soils in California affecting such diverse crops as artichokes, cotton, pepper, pistachio, potato, strawberry, tomato, watermelon, and a number of crucifer crops. The fungus produces characteristic black resting bodies called microsclerotia that survive in the soil for at least 10 years. As few as 2 microsclerotia per gram of soil can result in 100% disease incidence.

Continuous cultivation of strawberries increases the populations of pathogenic microorganisms including the microsclerotia of *V. dahliae* in the absence of soil fumigation. In contrast, crop rotations generally reduce the populations of pathogens because pathogens of one crop are unlikely to infect and multiply on an unrelated crop. Because of the wide host range of *V. dahliae*, crop rotations generally have been ineffective for the management of Verticillium wilt. However, all of this changed with our discovery of broccoli as an effective rotation crop for reducing the incidence of

Verticillium wilt in cauliflower (Koike and Subbarao, 2000). We had previously demonstrated in growers' fields that incorporation of broccoli residue in amounts representing what is left over after commercial harvest reduced the number of microsclerotia by more than 60% within one season and repeating the process the second year nearly eliminated the pathogen. This significantly reduced the incidence of Verticillium wilt on the subsequent cauliflower crops and the numbers of microsclerotia formed on the infected cauliflower roots. This was in contrast to a temporary reduction in the number of microsclerotia observed with the chemical fumigants; at the end of the cropping season the number of microsclerotia were back to the levels observed prior to fumigation. Additional studies determined that during production of the broccoli crop there was no reduction in the numbers of microsclerotia, but within a month after the residue incorporation, the microsclerotia declined and this reduction continued during the subsequent cauliflower crop. These effects were observed regardless of the irrigation methods and regimes employed. In a related study, we also demonstrated that fresh broccoli to be significantly more effective than dry broccoli, and to maximize broccoli-mediated pathogen attrition in soil, the residue should be incorporated when the soil temperature is at least 20 C. Rotations with broccoli also significantly reduced the soilborne sclerotia of Sclerotinia minor and the incidence of lettuce drop.

The mechanisms by which broccoli residue acts on soilborne pathogens could be chemical, biological, or both. During decomposition of crucifer residues, enzymatic degradation of glucosinolates (group of chemicals characteristic in crucifer crops) produces sulfides, isothiocyanates, thiocyanates, and nitriles. These chemicals have been attributed to reduce propagule numbers of a range of pathogens. Because these chemicals are volatile, their effects on soilborne pathogens, particularly on the microsclerotia of V. dahliae, can at best be considered transient. Recent work by others and us has shown that the primary mechanism of broccoli-mediated suppression of *V. dahliae* microsclerotia may be the enhancement of antagonistic soil microorganisms.

Materials and Methods

Based on the success of rotations of broccoli crop with cauliflower and lettuce for the management of Verticillium wilt and lettuce drop, respectively, we began testing the effect of rotations of broccoli, brussels sprouts, and lettuce with strawberries for the management of Verticillium wilt and other soilborne diseases. Experimental plots were set up at the Monterey Bay Academy in Watsonville in soil naturally infested with *V. dahliae* microsclerotia. Treatments were replicated 4 times with 2 beds per replicate and each treatment block was 25 ft long. Strawberry was grown in the plots in the 1996 season, followed by vegetable rotation crops during the 1997 season. After harvest, all vegetable crop residues were flail shredded, air dried on the surface for a minimum of two days and incorporated into the soil using a rototiller. Four weeks after incorporation, the beds in all plots were reworked for the next crop cycle. Strawberry (cultivar Selva) was grown in all treatment plots during the 1998 season to assess the effects of different rotation treatments and the experiments were repeated during the 1999-2000 season. Plots fumigated with methyl bromide+chloropicrin (57:43 at 325 lbs/A) were used for comparison with rotation treatments.

All strawberry plots were managed with standard commercial practices with harvest of culls and marketable yields collected on a weekly basis. Plant diameters and assessment of Verticillium wilt incidence and severity were collected at periodic intervals. The disease severity estimate was done on the scale of 0 to 8, where 0 = healthy plant, 2 = moderately stunted, 3 = moderately stunted, slight rosette of dead leaves, 4 = moderately stunted, moderate rosette, 5 = significantly stunted, slight rosette, 6 = significantly stunted, moderate rosette, 7 = significantly stunted, significant rosette, 8 = dead plant. Soil samples to determine the densities of *V. dahliae* propagules and total *Pythium* population were collected at beginning and at the end of the rotational crop, and every month after the start of the strawberry crop.

Results

Inoculum levels of *V. dahliae* were influenced by the crop that was grown in the soil (Figure 3). Broccoli rotations reduced the inoculum significantly and levels remained consistently low throughout the sampling period. Brussels sprouts also reduced inoculum, but to a lesser degree than broccoli whereas lettuce had a slight stimulatory or neutral effect on pathogen inoculum levels. Total populations of *Pythium* spp. were not influenced by crop rotation strategy. However, since there are differences in aggressiveness of various *Pythium* species on strawberry, additional studies are in progress to evaluate the influence of crop rotation on specific species.

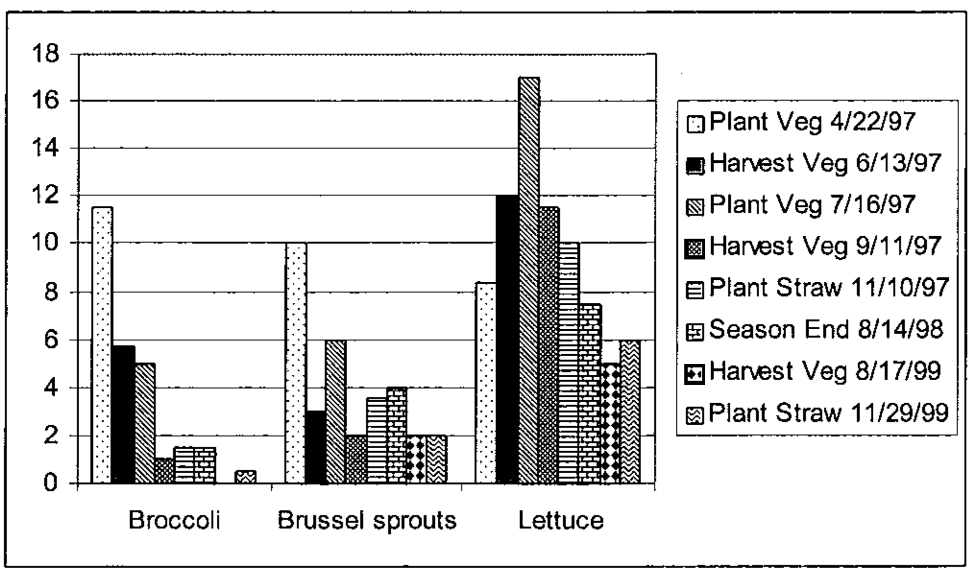

Figure 3. Effects of crop rotation on inoculum densities of *Verticillium dahliae* (microsclerotia/g soil) at MBA

The rotation treatments had a significant effect on the Verticillium wilt disease severity rating during all of the observation points (Figure 4). Strawberry plants grown in lettuce rotation treatment plots had the highest disease severity rating in both seasons. Strawberry plants in broccoli rotation treatment showed a consistently lower disease severity than in the rest of the crop rotation treatments during the season. Strawberry plant canopy diameter also was higher in the broccoli rotation treatment compared with lettuce treatment. Methyl bromide and chloropicrin fumigation produced the highest marketable strawberry yields (Figure 5). While there was a 23% reduction in yield for the broccoli rotation plots in 1998, this was significantly better than the 39% yield reduction encountered with the lettuce rotation plots.

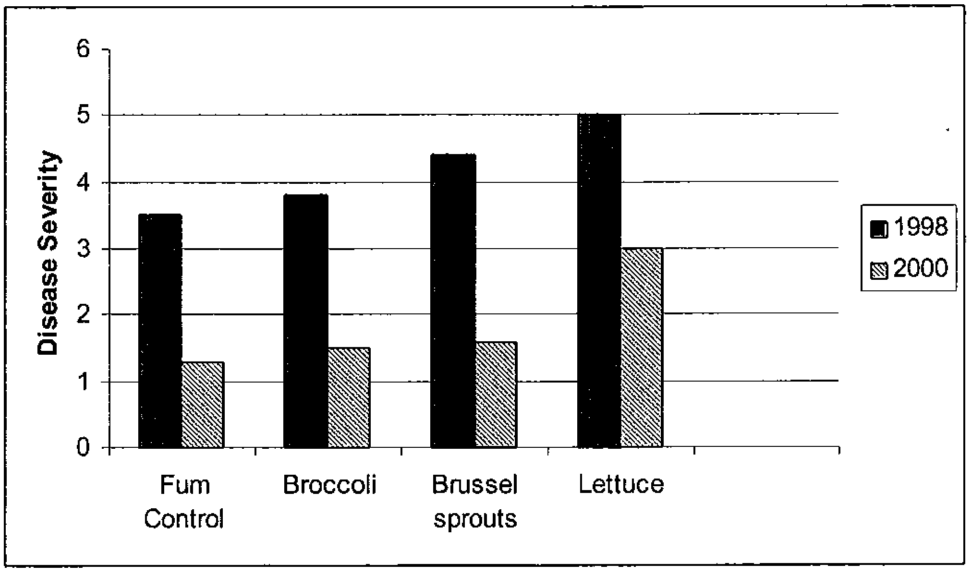

Figure 4. Crop Rotation Experiment – MBA Disease Severity Ratings

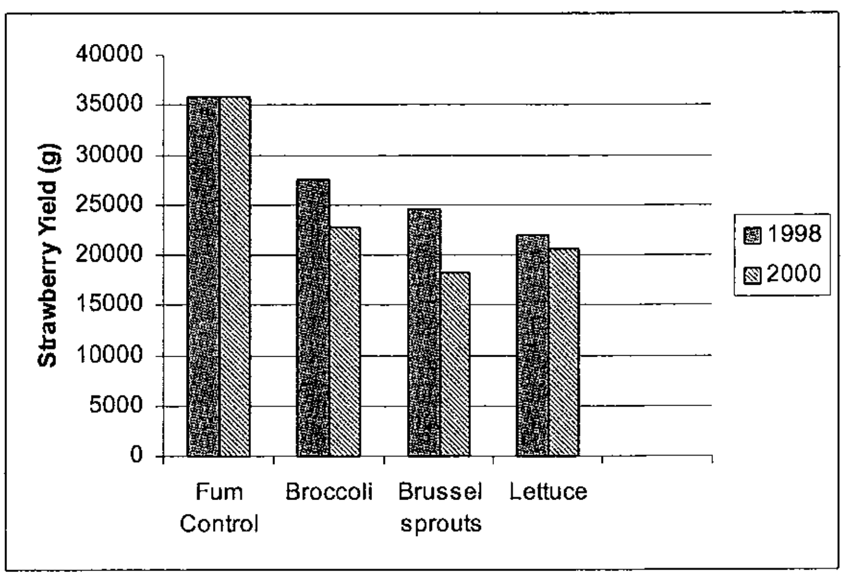

Figure 5. Crop Rotation Experiment – MBA Strawberry Market Yield

Similar experimentation is in progress at the USDA research plots in Salinas where *V. dahliae* is not a production problem to evaluate the influence of crop rotation on root rotting pathogens. The studies at the MBA site have recently been expanded to include larger test plots as well as the addition of plots in an organic production system.

3. **Organic Composting with High Nitrogen Amendments (Duniway)**

There is evidence that some composts and other organic amendments of soil can suppress soil-borne plant diseases and generally benefit plant growth. High-nitrogen organic amendments, reported to reduce Verticillium wilt in other cropping systems, were used in a field experiments on strawberry, starting with applications into pre-formed beds. Nonfumigated ground was prepared and listed into beds, amendments incorporated, drip tape and plastic mulch installed, and irrigated. Blood, feather, and fish meal applied to beds 5 weeks before planting at 2, 4, and 8 tons/acre treated area, respectively, reduced pathogen populations and the incidence of Verticillium wilt in Camarosa significantly. However, they also caused phytotoxicity and, therefore, did not give increases in yield proportional to levels of disease reduction. The effects of the same amendments at lower rates were insignificant. Chicken manure and mature compost (8 and 12 tons/acre, respectively), as well as stabilized urea, did not reduce Verticillium wilt significantly. Major transitions in soil microbiology, ammonia, and pH occurred as expected following additions of high nitrogen amendments.

In cooperation with Coastal Berry, a 0.3 acre experiment was initiated September, 1999, on new ground at MBA. The field was being grown organically and contained significant populations of *Verticillium dahliae*. The field was divided into 3 replicate blocks, 12 units each containing blood, feather, or fish meal at rates between 0-6 tons/acre. Soil was prepared and amendments incorporated on the flat, and then sprinkler irrigated. Beds were made later and planted with Aromas by normal practice. Broadcast applications of blood or fish meal at 4 and 6 tons/acre or feather meal at 2 and 3 tons/acre reduced populations of *V. dahliae* in soil and the incidence of Verticillium wilt significantly in both 2000 and 2001 (Figure 6). There was no phytotoxicity in these experiments. Effects on yield were small because harvest was discontinued in August only 3-4 weeks after the major disease increase occurred. Had the Aromas plants been kept in production longer, yield benefits would have been larger. Effects carried over from these soil amendments, with and without retreatment, are being determined in 2001-02. These experiments provide valuable information on rates of soil amendments and conditions that reduce Verticillium wilt and avoid phytotoxicity.

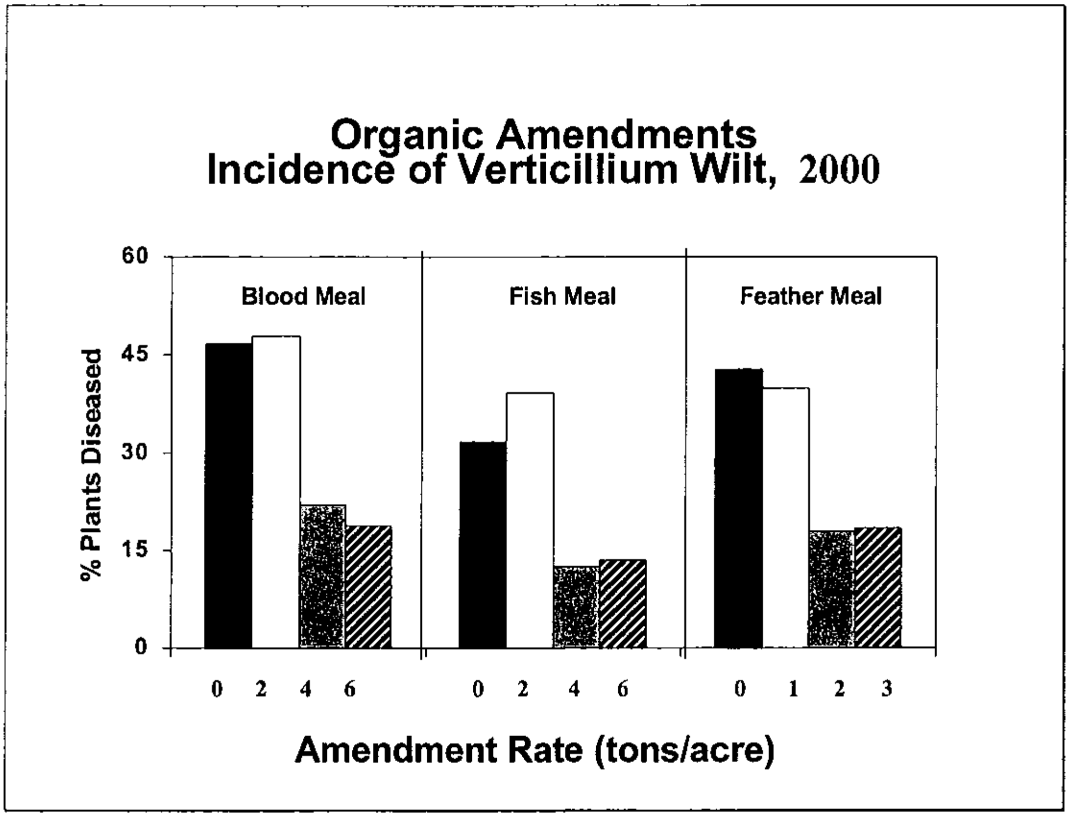

Figure 6. Effects of high-nitrogen organic amendments on the incidence of Verticillium wilt in Strawberry. Blood, fish, or feather meal was added to soil at the rates given before beds were made for planting Aromas in the fall of 1999. The percentage of plants with disease symptoms was measured in August, 2000.

4. **Colored Tarps (Fennimore, also support by UCSAREP BASIS grant)**

Three studies to evaluate the weed control efficacy of several polyethylene mulch colors were initiated September of 2000 at Monterey Bay Academy (MBA) in Watsonville (two studies) and at Martinez Farms of Oxnard, CA. One of the studies, at MBA, was established in a certified organic field and all inputs were consistent with organic production practices. Two conventional trials were established, one in Oxnard and the other in MBA, on ground that was fumigated with chloropicrin at a rate of 180 and 187 pounds per acre, respectively.

Strawberry transplants were established in all plots during October 2000. A randomized complete block design with four replications was utilized. Mulch colors in both MBA studies included: black, white (on black), brown, green, yellow (on brown), blue, clear, and red (on brown) polyethylene, plus bare ground was included as the control. The mulch colors at the Oxnard trial were silver, black, blue, clear, white and green.

In the organic system, weeds from two 0.25 m^2 quadrates per plot were harvested at about six-week intervals, identified by species and weighed. In the conventional system, weed density counts were made at about six-week intervals. Four nylon mesh bags with one hundred seeds each of little mallow, redstem filaree and California burclover (*Medicago polymorpha*) were placed on the soil surface under the tarp of each plot. The purpose of these seed bags was to determine the effect of light and temperature under the various mulches on weed germination. One set of the bags was removed at two-month intervals. Upon removal, the seeds were examined and the number of germinated seeds counted.

Plant diameters were assessed twice during the season at the MBA trials by measuring the diameters of 20 plants per plot in two directions, both parallel and perpendicular to the plant row. Total marketable yield was also sampled at these trials from twenty-four plants per plot in the organic system and 40 plants per plot in the conventional system.

Organic strawberry colored mulch evaluation.

Weed biomass was reduced under the black, brown, green, red (on brown), white (on black) and yellow (on brown) polyethylene mulches compared to bare ground (Table 4). Plant growth was enhanced by all of the colored mulches compared to bare ground. The highest production of marketable fruit came from the plots covered with black, brown, green, red (on brown), white (on black) and yellow (on brown) mulches.

Table 4: A comparison of the effect of colored polyethylene mulches on weed growth, plant growth and yield in organic strawberries at MBA.

Tarp color	Weed biomass g/0.25 m^2	Plant diameter (cm)[a]	Fruit yield Crates/acre[b]
Bare ground	755.6 b	17.44 c	747.17 b
Clear	1294.1 a	19.32 bc	1072.70 ab
Black	213.9 c	20.55 ab	1582.27 a
Blue	524.1 b	20.17 ab	1144.05 ab
Brown	43.3 c	21.55 a	1499.31 a
Green	124.6 c	20.45 ab	1345.96 a
Red (on brown)	196.3 c	21.33 ab	1374.44 a
White (on black)	156.3 c	19.66 ab	1391.11 a
Yellow (on brown)	59.5 c	20.37 ab	1284.74 a
LSD 0.05	275.8	2.10	

[a] Mean diameter of 20 plants per plot.
[b] Marketable fruit yield.

Conventional strawberry colored mulch evaluation.

At the MBA site, weed density was lower in the black and green polyethylene treatments than the other colored mulches (Table 5). Blue mulch had the highest weed densities. Weed seed germination in the installed seed bags was highest under the clear mulch and lowest under the green mulch. Plant growth and yields were enhanced by the clear mulch, but were reduced by the white mulch.

Table 5: Effect of mulch color on weed density (no./ft^2), seed germination per bag, plant diameter and yield of conventional strawberries in colored polyethylene mulches at Watsonville, CA .

Polyethylene mulch color	Weed density (no./125ft^2)	Weed germination (no./bag)	Plant diameter (cm)[a]	Yield (crates/acre)[b]
Bare	20.00 bcd	16.00 ab	22.50 de	4595.9 bc
Clear	29.25 ab	22.75 a	24.98 a	5670.6 a
Black	7.00 d	14.00 ab	23.96 ab	4940.2 b
Yellow (on	25.00 bc	16.00 ab	23.21 bcd	4805.7 b
brown)	13.00 cd	6.50 b	23.65 bc	4798.9 b
Green	22.25 bcd	13.50 ab	22.94 bcde	4765.8 b
Red (on brown)	16.75 cd	11.25 ab	22.64 cde	4654.5 bc
Brown	38.25 a	9.25 ab	23.21 bcd	4551.1 bc
Blue	21.00 bcd	11.00 ab	22.04 e	4122.6 c
White (on black)				
LSD 0.05	2.49	14.15	1.13	

[a] Mean diameter of 20 plants per plot.
[b] Marketable fruit yield.

At the Oxnard site, weed densities were highest in the plots covered with clear mulch (Table 6). More weeds were present in plots with blue and white mulch than plots with the other colored mulches. More weed seeds germinated under the white colored mulch than the other colored mulches, and the fewest seeds germinated under the clear and black mulch. The soil under the clear mulch was dry due to high soil temperatures and the fact that the seed bags were 12 inches away from the drip tape resulted in low germination rates. These results indicate that black and green mulches provide the highest level of weed control.

Table 6: Effect of mulch color on weed density (no./ft^2) and seed germination per bag at Oxnard, CA

Polyethylene mulch color	Weed density (no./ 400ft^2)	Seeds germinated in bags (no./bag)
Clear	86.00 a	7.00 b
Blue	61.00 ab	20.25 ab
White	55.75 ab	31.75 a
Silver	28.00 b	16.50 ab
Black	23.25 b	6.25 b
Green	20.00 b	19.00 ab
LSD 0.05	41.59	16.19

5. Solarization (Fennimore)

Three treatments were used to compare the effects of solarization: a control, a single layer of plastic and a double layer of plastic with an air space between the two layers. Nylon mesh bags containing one hundred seeds each of four weed species were placed under each tarp or in the open air (control). Species of weed seed chosen for this experiment include: common purslane (*Portulaca oleracea* L.), little mallow (*Malva parviflora* L.), redstem filaree (*Erodium cicutarium* L'Her.) and prostate knotweed (*Polygonum aviculare* L.). Temperatures were monitored under the single and double layer tarps using Hobo® Pro H08 temperature recorders (Oneset Computer, Pocasset, MA). The seed were exposed to the treatment from September 2 through October 4, 2000 (32 days elapsed). Weed seed were removed at the end of the period, and seed viability was assessed using tetrazolium assays (Grabe, 1970). The study was arranged in a randomized complete block design with 4 replicates, and was located on a commercial farm near Watsonville, CA.

The soil temperatures in the double layer tarp treatment exceeded 50°C for 9 hours during the 32-day period, while soil temperatures in the single layer tarp never exceeded 50°C. Purslane seed viability was reduced by the double layer tarp treatment, but not by the single layer tarp treatment (Table 7). Seed viability of the other species was not affected by any of the solarization treatments (data not shown).

Table 7. The effect of single and double layer plastic on purslane seed viability.

Treatment	Purslane viability (%)
Untreated	85.8
Single layer	79.3
Double layer	51.8
LSD 0.05	14.7

6. Non-Chemical Weed Control (Fennimore)

Ozone.

Trials were established at two sites: Prunedale, CA and Spence USDA Farm, Salinas, CA to evaluate the efficacy of ozone as a soil disinfestant. The Prunedale site was non-fumigated and the Spence study was conducted on a certified organic field using organic-approved inputs. Nylon mesh bags containing 100 annual bluegrass (*Poa annua*) seeds were placed slightly beneath the soil surface of all plots before the ozone application and retrieved after the ozone was applied. Seed viability was determined using tetrazolium as described above. Weed density counts were taken three times during the season. A randomized complete block design with 4 replicates was used at both sites.

Prunedale. In November of 2000, three levels of ozone (100, 200, and 400 lbs/acre) were injected into the soil through drip irrigation tubing buried 5-inches deep. Additional treatments included the bio-integrated system alone or in combination with 100 lbs/acre ozone. Napropamide at 4.0 lbs/acre was included as a commercial standard.

Spence Farm. Treatments included ozone at 100, 200 and 400 lbs/acre injected through drip irrigation line as described above.

The first weed count taken at the Prunedale trial indicated that the plots treated with napropamide had the fewest weeds (Table 8). Ozone did not provide control of any weeds. The bio-integrated system alone or with ozone at 100 lbs/acre both had lower total weed densities than the control. The bio-integrated system alone or with ozone at 100 lbs/acre had lower bluegrass densities than the control. None of the ozone treatments at the Spence site had any effect on weeds (data not shown). There were no differences in bluegrass seed viability at either site (data not shown). Future work with ozone is not recommended as a soil disinfectant. The bio-integrated system continues to provide moderate levels of weed control as we have seen previously (Fennimore & Bull, unpublished). Further work with the bio-integrated system is recommended.

Table 8. Evaluation of weed control provided by ozone and the bio-integrated system's effect on weed densities at Prunedale, CA.

Treatment	No. total weeds (86.7/ft^2)	No. bluegrass (86.7/ft^2)
Control	180.50 a	141.74 a
Ozone 100 lbs/acre	184.00 a	95.00 ab
Ozone 200 lbs/acre	152.75 a	97.50 ab
Ozone 400 lbs/acre	122.50 ab	95.00 ab
Bio-integrated system	63.50 bc	29.25 cd
Ozone 100 lbs./acre + bio-integrated system	62.00 bc	43.00 bcd
Napropamide 4.0 lb/A	17.75 c	0.75 d
LSD 0.05	73.47	60.86

7. Pest Management Timing – Plant Back Timing (Duniway)

In order to ensure that the pest management techniques developed and demonstrated above are available for immediate use by the industry, assessments of the impacts of these techniques on plant-back timing was proposed. This was of primary importance for organic amendments applied to beds where earlier experiments showed some phytotoxicity of the treatments to strawberries after transplanting. The more recent methods used to apply organic amendments on the flat, however, have proven to be superior to bed applications, and they have not caused phytotoxicity. Therefore, plant-back timing was not researched further in this grant period.

8. Cultivar Tolerance to Non-Chemical Techniques (Duniway, Browne)

Duniway – Tolerance to Verticilium Wilt

Prior to the development of current fumigation practices, Verticillium wilt was a highly destructive disease of strawberries in California. Today, it is still a high-risk disease for strawberry growers whenever soil fumigation procedures are not fully effective. Verticillium wilt control following the phase-out of methyl bromide in 2005 is likely to require a combination of cultural and chemical approaches. In addition to researching management of Verticillium wilt with alternative fumigants, crop rotations, and organic amendments, we researched the dynamics of *V. dahliae* populations in soil, disease relationships to inoculum levels in soil, and methods to better screen strawberry lines and varieties for genetic tolerance. In 1999-2000 and 2000-01, several California varieties ranging in tolerance to Verticillium wilt were grown in replicated plots without fumigation at MBA to determine relationships between *V. dahliae* populations in soil and disease development. *Verticillium* populations in soil were very dynamic and final disease incidence in Camarosa greatly exceeded that in other varieties, but all varieties tested so far were fairly susceptible. Unfortunately, the data obtained suggests that the inoculum threshold for Verticillium wilt is very low, but lower for Camarosa than for Diamante or Aromas (Figure 7). While relationships of disease to initial inoculum levels varied somewhat between years, the effect of initial inoculum on the total yield of Camarosa was significant, e.g., inoculum levels higher than 2 ms/g soil reduced yield. Although there is a year-by-variety interaction, the overall results obtained so far suggest the following relative ranking of varieties for susceptibility to Verticillium wilt (most to least susceptible): Camarosa, Laguna, Diamante, Aromas, Seascape, Selva, Chandler, and Hecker.

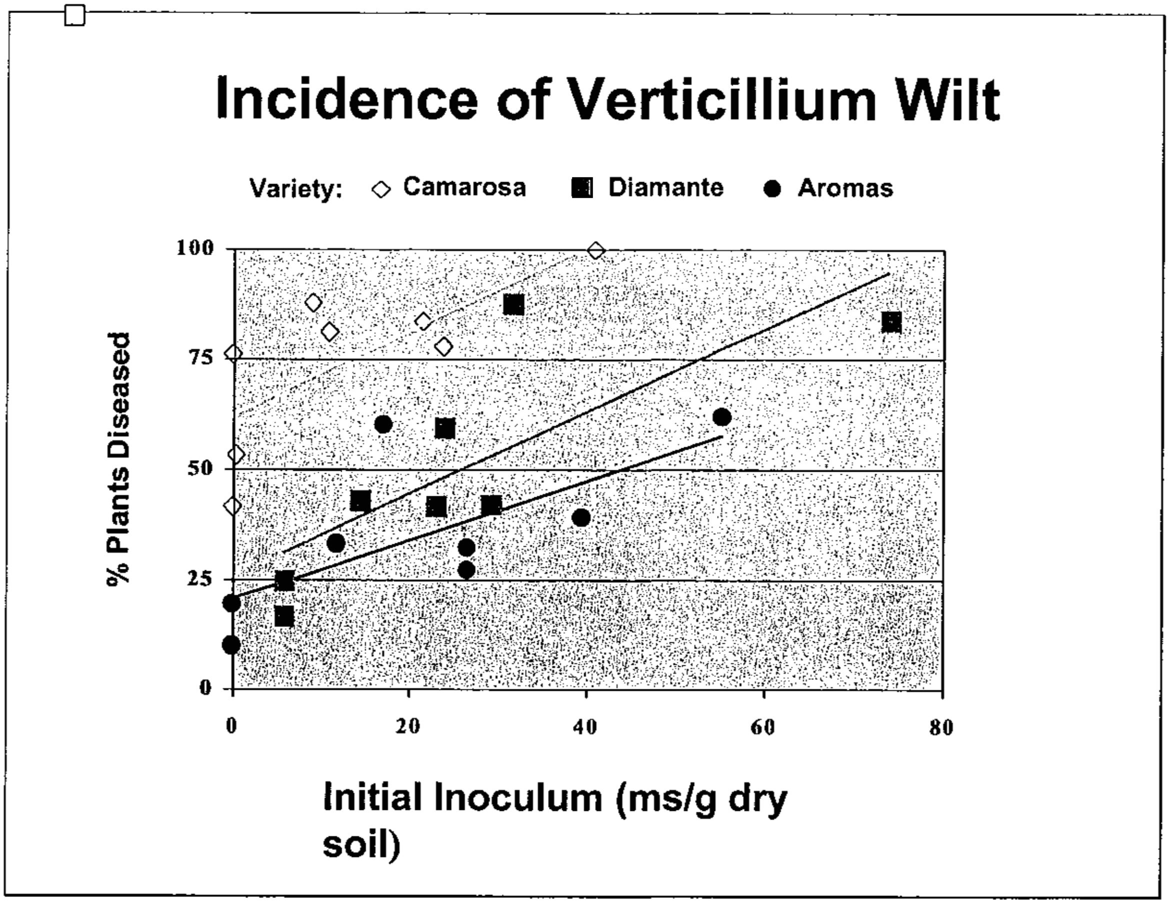

Figure 7. Final incidence of strawberry plants with Verticillium wilt, for the varieties Camarosa, Diamante, and Aromas, plotted as a function of the initial inoculum level of *Verticillium dahliae* measured in soil at planting.

Materials and Methods

Cultivar Tolerance to Non-Chemical Techniques. Among the most important factors determining adaptability of strawberry cultivars to non-chemical techniques is their resistance to soilborne pathogens. We evaluated resistance to two important *Phytophthora* species affecting California strawberries, *Phytophthora cactorum*, causal agent of crown and root rot and plant collapse, and *Phytophthora fragariae* var. *fragariae (Pff)*, causal agent of red stele disease.

Tolerance of strawberry cultivars to *Phytophthora cactorum*. During two field seasons (1998-99 and 1999-00) tolerance of seven UC strawberry cultivars to *P. cactorum* was determined under field conditions at Monterey Bay Academy (MBA) by comparing their performance on plots artificially infested with the pathogen to that in non-infested plots. The plants used in the tests were grown at a high elevation nursery using standard practices. Subsampling of the planting stock in each year indicated that it was relatively free from contamination by *P. cactorum*. Except for the soil infestation treatments, standard cultural practices were employed at MBA (i.e., preplant flat fumigation with approx. 350 lb/A methyl bromide:chloropicrin 67:33 under standard high density polyethelene mulch, use of 52-inch beds mulched by black polyethylene, two plant rows per bed spaced 14 inches apart and underlain by slow-release fertilizer, two drip lines per bed spaced 8 to 10 inches apart and 2 to 4 inches deep, and standard irrigation, fertilization, and pest management practices). No systemic fungicides active against *Phytophthora* spp. were applied. In late October to early November of each growing season, the soil infestation treatments were imposed. Inoculum of four strawberry isolates of *P. cactorum* that had grown for 1 month on solid V8 juice-vermiculite-oat seed substrate was rinsed to remove unassimilated nutrients, combined, and mixed into planting holes at MBA at a rate of 100 ml inoculum per hole. Sterile substrate was mixed into planting holes for the control plots at the same rate. Within 1 day after soil infestation, the infested and non-infested plots were planted with the tested cultivars. For each combination of cultivar and inoculum treatment, there were four replicate 10-plant plots. Susceptibility was determined by comparing cultivar performance in the non-infested and infested plots; the variables monitored included monthly disease ratings for each plant (0=no disease, 5=dead plant, 2,3, and 4=successive increments of plant stunting, discoloration, and wilting), marketable fruit yields (weekly and cumulative), and incidence of plant mortality.

Browne – Tolerance to *Phytophthora sp.*

Tolerance of strawberry cultivars to *Phytophthora fragariae var. fragariae*. In 2000-01 the seven UC cultivars tested with *P. cactorum* at MBA as well as seven additional cultivars occasionally used as *Pff* race differentials were evaluated for resistance to *Pff* in growth chamber and greenhouse experiments using methods developed by Van de Weg (Van de Weg, W. E., Giezen, S., Henken, B., denNijs, A.P.M. 1996). In preparation for the tests, daughter plants were rooted in potting soil in the greenhouse. About 4 weeks after rooting, the plants were gently rinsed free from the soil, and their roots were dipped into a mycelial slurry of a mixture of four California isolates of *Pff*, transplanted into non-infested potting soil, and subjected to soil flooding for 48 hr. Control plants were treated in the same way, except that they were dipped into a sterile agar slurry. After flooding, all plants were watered every other day and the soil was allowed to drain freely. A 16 hr photoperiod was maintained, with air temperature at 10 C (night) and 17 C (day). In each of three experiments, there were four replicate plants per combination of inoculum and cultivar. One month after inoculation, each plant was gently rinsed free from adhering soil and evaluated for incidence and severity of disease using a method modified after van de Weg Van de Weg (Van de Weg, W. E., Giezen, S., Henken, B., denNijs, A.P.M. 1996). The percentage of infected root tissue (PIRT) for each plant was determined as follows: five randomly selected root pieces were cut from each plant at the crown and their total length measured. The roots were then cut transversely and the percentage of the discolored root length containing oospores of *Pff* was determined using a microscope.

Results and Discussion.

Tolerance of strawberry cultivars to *Phytophthora cactorum.*

P. cactorum generally caused more disease in 1999 fruiting season than in the 2000 season. Overall, Diamante, Gaviota, and Pajaro were relatively susceptible to *P. cactorum*; when grown in plots infested by the pathogen, their marketable fruit yields averaged from 14 to 52% of the yields in plots without the pathogen (Fig. 5 A,B). On the other hand, Aromas, Pacific, and Parker were relatively resistant; in the infested plots their yields averaged 68 to 102% of the yields in noninfested plots. Camarosa had an intermediate response and in infested plots yielded an average of 43 to 72% of the control yields. Incidence of plant mortality associated with infection by *P. cactorum* was greatest among the cultivars that suffered large yield reductions in the infested plots (Figure 8 C,D).

The results suggest a positive outlook for development of California strawberry cultivars with a high level of tolerance to *P. cactorum*. Among four of the most popular UC cultivars released within the last few years, high tolerance to *P. cactorum* (Aromas, Pacific) as well as high susceptibility to the pathogen (Diamante, Gaviota) was determined. This suggests that it will be feasible to select new cultivars that combine good horticultural traits with moderate to high tolerance to the pathogen, thereby reducing reliance on methyl bromide for control of the disease.

Tolerance of strawberry cultivars to *Phytophthora fragariae* var. *fragariae.*

In all three tests, the seven California cultivars (Aromas, Camarosa, Diamante, Gaviota, Pacific, Pajaro, and Parker) and only one differential (Del Norte) were susceptible (PIRT 30 to 81) (Figure 9 A-C). The other differentials (Aberdeen, Blakemore, MD 683, Sparkle, Stelemaster and Yaquina A) and all noninoculated controls had no disease. Molecular tests indicated that Blakemore was misidentified, and hence it is referred to as "False Blakemore" in this report.

The results indicate that many popular UC strawberry cultivars do not possess good resistance to *Pff*. None of the seven tested UC selections expressed resistance to *Pff*, including those that had high levels of tolerance to *P. cactorum*. Field observations have suggested that Chandler, another UC cultivar, also is susceptible to the pathogen. Screening of additional UC and private strawberry selections, as well as evaluation of related germplasm may help determine sources of resistance to *Pff* that could be incoparated in future California strawberry cultivars, thereby lessening dependence on pre-plant soil fumigation for strawberry production.

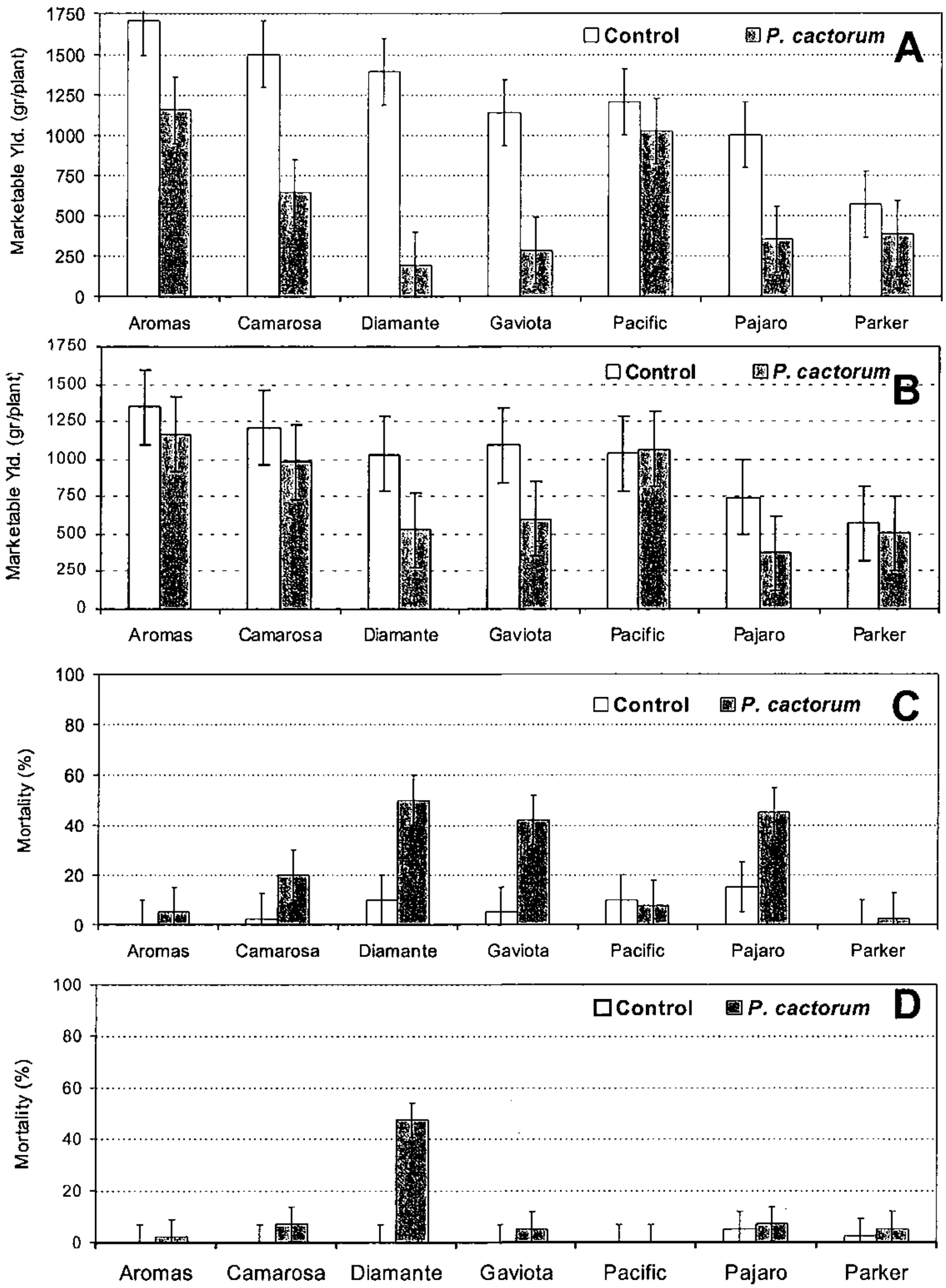

Figure 8. Relative resistance of seven UC strawberry cultivars to disease caused *Phytophthora cactorum* in Monterey Bay Academy field plots. **A** and **B**, effects soil infestation with *P. cactorum* on cumulative marketable fruit yields in the 1998-99 and 1999-00 fruiting seasons, respectively. **C** and **D**, effects of soil infestation with *P. cactorum* on

incidence of plant mortality in the 1998-99 and 1999-00 fruiting seasons, respectively. Vertical bars delimit 95% confidence intervals.

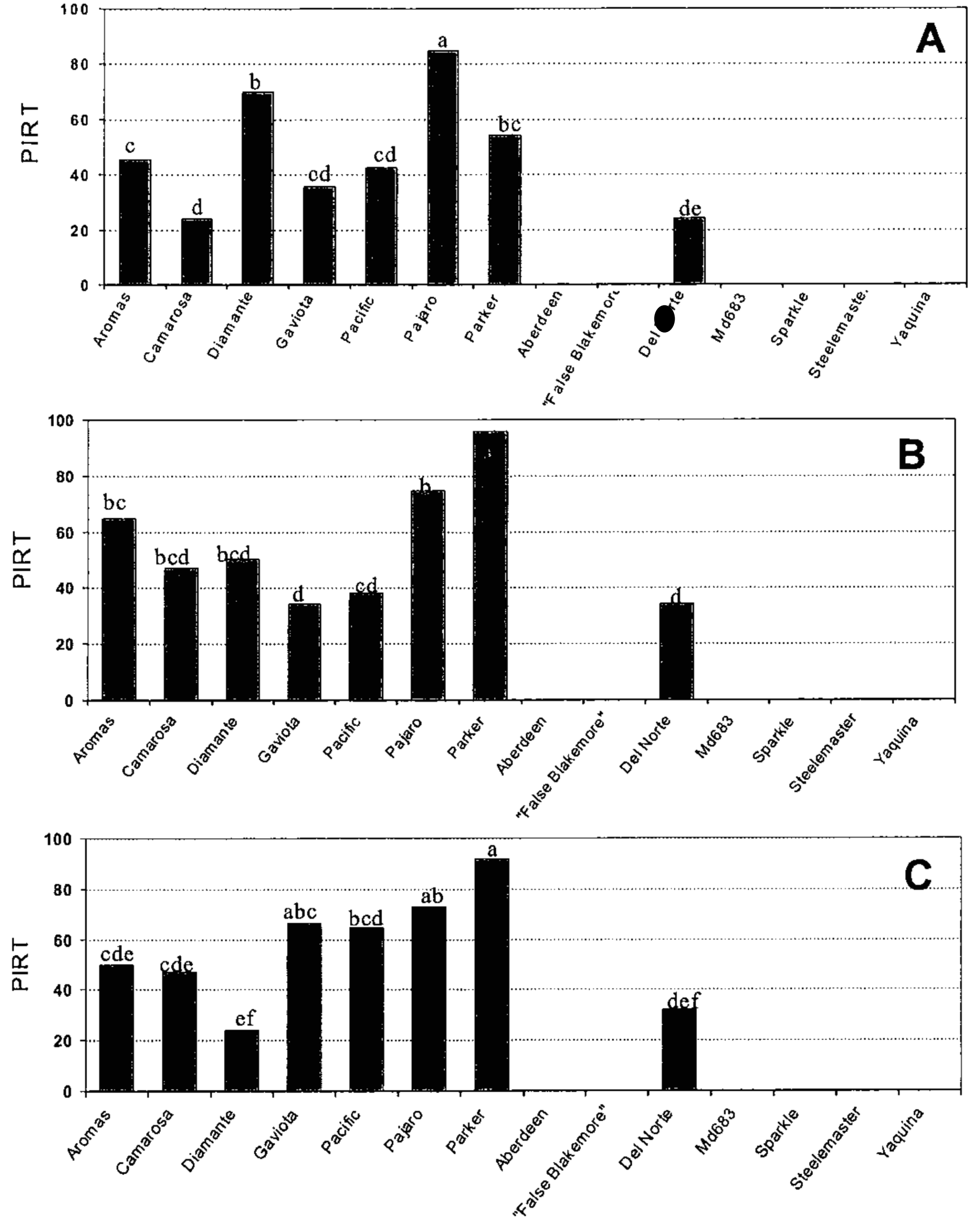

Figure 9. Relative susceptibility of seven UC strawberry cultivars and seven supposed race diffential cultivars to red stele disease caused by *Phytophthora fragariae* var. *fragariae* (*Pff*) in growth chamber (**A** and **B**) and greenhouse tests (**C**). Susceptibility was assessed by determining the percentage of infected root tissue (PIRT, based on microscopic

examination) after inoculation with *Pff*. "False Blakemore" indicates a cultivar determined to be misidentified as Blakemore. Means on a graph without letters in common are significantly different (Waller-Duncan k ratio test).

9. **Coordination and Demonstration with Chemical Alternatives Research (CSC)**

The following Field Days we held in 2001 for growers in each of the major strawberry growing regions.

Annual Strawberry Research Conference, February 7, 2001, 8: 30 AM – 3: 30 PM, Arts Building, Santa Cruz County Fairgrounds. (90 growers in attendance)

Strawberry Research Conference, University of California South Coast REC, Irvine, CA, March 14, 2001. (230 growers in attendance)

2001 Oxnard Strawberry Field Day, Thursday, March 29, 2001, 9:00 a.m. – 1:00 p.m., Martinez Berry Farms. (175 growers in attendance.)

Santa Maria Strawberry Field Day, Tuesday, April 10, 2001, Gold Coast Farm – Ron Burk, 0.4 miles East of Highway 101 on Stowell Road. (95 growers in attendance)

Monterey Bay Academy Strawberry Research Field Day, Wednesday, June 27, 2001, 9 a.m. – 12:20 p.m., Monterey Bay Academy. (150 growers in attendance)

Strawberry Research Field Day, USDA Agriculture Research Station, Salinas, Tuesday, July 10, 2001; 9-12 AM.

Researchers made presentations of their data either in talk or poster form, and distributed detailed handouts on their research. Simultaneous Spanish translation was available at each of the Field Days. Agendas for each of the Field Days are found in Appendix B. Relevant handouts distributed at these meetings are located in Appendix C. In addition a list of Strawberry Commission Pink Sheets of the relevant research, distributed to all growers, are listed in Appendix D.

Comparison of the non-chemical projects with chemical alternatives were primarily demonstrated in the field at the Oxnard Field Day, the MBA Field Day, and the USDA Field Day in 2001.

10. Economic Assessment of Non-Chemical Alternatives

Lack of efficacy or preliminary nature of the results on beneficial amendments, organic composting (which is very costly because of the extremely high amount of material, tons per acre, required), solarization, and non-chemical weed control were such that full economic assessments of the techniques were premature. Crop rotation was promising, yet yield losses would not sustain current operating costs for majority of growers in California. Colored tarps are already in use in conventional culture in some regions, but must be balanced economically with cultivar and market timing preferences because of the impact of the colored tarp on soil temperature and plant growth. Cultivar resistance ultimately would be an excellent solution, but breeding programs require decades for implementation.

Project Summary Form

1) Proposal Title

Multi-Disciplinary Approach to Methyl Bromide Replacement in Strawberries Using Non-Chemical Alternatives

2) Principal Investigator

J Duniway, S Fennimore, C Bull, G Browne, F Martin

3) Alternative Practices

Organic Amendments with Beneficial Microorganisms, Crop Rotation, Organic Composting with High Nitrogen Composts, Tarps and Films, Solarization, Non-Chemical Weed Control, Plant-Back Timing with Non-Chemical Techniques, Cultivar Tolerance to Non-Chemical Techniques, Coordination and Demonstration with Chemical Alternatives Research, Economic Assessment of Non-Chemical Alternatives

4) Summary of Project Successes

Beneficials, crop rotation, organic composting, solarization showed some initial promise, but much more work required. Black and green tarps worked best for weed control of all of the colored tarps. Ozone had poor efficacy. Cultivars tested resistance to Verticilium, but some had promising resistance to Phytophthora. Conducted 6 well attended Field Days across growing regions in which aspects of this work were presented.

5) Number of Participating Growers	4	12) Number of Field Days	6
6) Total Acreage in Project	2	13) Attendance at Field Days	740+
7) Project Acreage Under Reduced Risk	2	14) Number of Workshops & Meetings	NA
8) Total Acres of Project Crop	250	15) Workshop Attendance	NA
9) Non-Project Reduced Risk Acres	50	16) Number of Newsletters	5
10) Number of Participating PCAs	5	17) Number of Articles	2
		18) Number of Presentations	3+

11) Cost Assessment

Poor efficacy and preliminary nature of most non-chemical treatment results did not allow detailed economic analysis.

19) Other Outreach Activities

CA Strawberry Commission website has all Research Pink Sheets available to growers

FOR OFFICIAL USE ONLY

Contract Number ______ Project ID ______

DPR ID# ______ Contract Manager ______

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APPENDICES

Appendix A.
California Strawberry Crop Profile

PEST MANAGEMENT EVALUATION AND CROP PROFILE

STRAWBERRIES IN CALIFORNIA

October 29, 2001

CALIFORNIA STRAWBERRY COMMISSION
180 Westridge Drive, Suite 101
P. O. Box 269
Watsonville, California 95077-0269

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CROP PROFILE
STRAWBERRIES IN CALIFORNIA

October 29, 2001

EXECUTIVE SUMMARY

Strawberry production in California is intensive and highly productive, with productivity per acre being over 4 times higher than that of most other states. This productivity is accomplished, in part, through an extensive pest management program using a wide variety of cultural practices in conjunction with biological and chemical control techniques. California's strawberry industry has a relatively small number of chemical tools available to them and, by 2005, the chemical used to manage the largest number of significant pests and diseases, methyl bromide, will no longer be available. The use of methyl bromide will be phased out with a 50% reduction in use mandated in 2001 and a 70% reduction in use in 2003, therefore, 2004 will be the last year that methyl bromide will be available to most growers. As a result, it is crucial to maintain as many of the existing pest management tools as possible to limit future losses in California's production and to maintain strong resistance management programs.

Integrated Pest Management. Strawberry production in California uses an integrated approach to pest management. In an effort to maximize the appropriate control of economically important pests, California growers recognize that a cost-effective program must ensure that pest management tools are not lost due to the onset of resistance. Pest levels are monitored closely to ensure that pest management decisions are initiated prudently and carefully coordinated. As a result, all growers use a mixture of cultural, biological, and chemical control practices to control economically important pests. This Crop Profile describes these practices.

Crucial Role of Fumigation. Soil fumigation prior to planting plays a central role in pest management and productivity for California's strawberry industry. In particular, one single pest management tool, methyl bromide combined with chloropicrin, is used extensively by California's strawberry industry to control a wide variety of soil-borne pests and diseases. With the exception of organically-grown fields, methyl bromide is essentially used on all California strawberry fruit production acreage and all nursery plant production, including nursery stock destined for organic acreage. This combination pre-plant fumigation has proven efficacious against disease agents such as soil-borne fungi that cause verticillium wilt, Phytophthora root and crown rots, anthracnose, black root rot, charcoal rot, and, significantly, other soil-borne pathogens of unknown etiology that impact strawberry plant yield and quality. Methyl bromide/chloropicrin treatments are also effective for arthropods (such as root weevils, cutworms, strawberry rootworm, white grubs, and garden symphylan and mealybugs), nematodes (such as foliar nematodes), and weed seeds of all species (with a few exceptions). The loss of methyl bromide, as discussed below, will have a significant impact on the productivity and most of the state's current pest management practices.

Important Pests. For strawberries in California, the most important arthropod pests are twospotted spider mites, Lygus bugs, cyclamen mites, western flower thrips, aphids, root weevils, cutworms, beet armyworms and whiteflies Nematodes are also important though, currently, they are controlled effectively through fumigation. Important diseases include botrytis rot, verticilium wilt, phytophthora crown and root rot, rhizopus fruit rot, mucor fruit rot, powdery mildew, common leaf spot, anthracnose, and other soil-borne pathogens of unknown etiology that reduce strawberry plant vigor, yield and berry quality. Botrytis, verticilium wilt and phytophthora have a significant impact statewide.

Level of Reliance on Chemical Treatments. Most pesticides are applied to approximately one quarter of the state's strawberry acreage (4). However, fumigant use, currently methyl bromide combined with chloropicrin, is practiced on all but the organically grown production acreage. From 1997 – 1999, fungicide use was also relatively high for some compounds with sulfur, captan, myclobutanil (RALLY), iprodione, thiram and benomyl being used on more than half the acreage (4). Only one insecticide and one miticide, malathion and avermectin respectively, were used on over half of the acreage in the same time period. Herbicides are not as widely used due to the effectiveness of methyl bromide as a pre-emergent herbicide and the common use of plastic mulch on California fields.

Vulnerable Chemicals Under FQPA. The California strawberry industry has become increasingly vulnerable under FQPA. Few chemical ingredients are registered for use on strawberries, a minor crop. The loss of any single fungicide will adversely impact the IPM practices used by growers and accelerate the onset of resistance. Similarly, loss of any of the insecticides available to the industry would have a significant adverse effect on resistance management and the use of beneficial organisms. The continued ability to have these pest management tools available so that they may be used for control of periodic or sporadic outbreaks could be crucial to the industry. NAPIAP (USDA) has produced a thorough evaluation of the potential impacts of the loss of individual pesticides on the industry (7). This document concludes that the loss of any of several existing pesticides would result in significant adverse impacts on California's strawberry industry.

Since publication of the 1999 California Strawberry Crop Profile, FQPA has had significant impact on the availability of pesticides used on strawberries. Use of the fungicide vinclozalin (Ronilan®) has been completely lost on strawberries. Use of the fungicide iprodione (Rovral®) has been reduced to a single pre-bloom application on strawberries. The PHI for carbaryl (Sevin®) use was raised to 7 days, making that pesticide virtually unusable on fresh production strawberries. Insecticides azinphos-methyl (Guthion®) and endosulfan (Thiodan®), while infrequently used, are currently being phased out on strawberries. Recent success stories include maintaining diazinon and chlorpyrifos uses thanks to efforts by EPA, USDA and the grower community. However, until the Cumulative Risk Assessment process for organophosphate insecticides (OPs) is complete at EPA (projected August 2002), all OP uses (which includes malathion and dibrom in addition to diazinon and chlorpyrifos) on strawberries are still vulnerable to FQPA. In addition, the aggregate and cumulative risk processes for fungicides has yet to begin, and new vulnerabilities may become apparent.

Vulnerable Chemicals to Other Regulatory Pressures. Non-FQPA, FIFRA-based issues on worker exposure and ecological effects are becoming more important drivers to the loss of pesticides uses. These impacts may not be felt for another two to three years and the degree of impact will depend upon the level of refinement EPA does on their worker exposure and ecological risk assessment processes. Ironically, those OPs that may survive FQPA and Cumulative Risk intact, may have more critical battles ahead with worker exposure and ecological effects issues. In addition, the manufacturer has removed benomyl (BENLATE) from the market, although thiophanate-methyl (TOPSIN M) is the same family of chemistry and mode of action and is still available.

Within the state of California, regulatory requirements are more restrictive than are those of US EPA. Even though methyl bromide will be phased out in 2005, CDPR continues to add new more restrictive permit regulations which further limit methyl bromide use even before the 2005 phase out. Methyl bromide is vulnerable to further restrictions for ambient air concentrations, which could further limit its availability in the crucial time of transition to alternatives before 2005.

Methyl Bromide and Alternatives Research. The year 2001 was the first year methyl bromide use dropped to the 50% of 1991 levels mandated by the Montreal Protocol. While availability of material to strawberry growers was not impacted significantly, increased prices were noticed in the marketplace. Methyl Bromide Alternatives research has produced preliminary indications of potentially successful combinations of alternatives. Drip applied materials show great promise, yet still face regulatory hurdles within the state of California. For instance, drip applied Telone® products registered in 2001 are beginning to be used but are severely limited as a total replacement product by the state imposed Township Caps. Chloropicrin is just beginning the re-evaluation process within the state and is vulnerable to more restrictions when the risk assessment is complete. MITC (methyl isothiocyanate) generators are further along in the risk assessment process and very vulnerable to further restrictions.

Two other very promising materials are just beginning the national registration process. Iodomethane and propargyl bromide will probably not see registration in the US until 2004 and 2005 respectively, and registration in California at least one year after that. Hence there is some concern these materials will not be available once methyl bromide is not longer available. If any single chemical has the greatest impact on strawberry production, soil fumigation is the one because it controls so many diseases and pests and weeds at once. During and after transition to alternatives, pesticide use may increase to control those pests not controlled by alternatives.

Use of Chemical Alternates. Use of new, reduced risk pesticides such as azadirachtin (NEEM OIL and NEEM OIL) and *Bacillus thuringiensis* (Bt) increased in 1999 (3% and over 20%, respectively)(4). While encouraging, the effectiveness of azadirachtin against some target insect pests is only moderate, and the target pest spectrum of Bt is limited to the Lepidoptera (worm) pests. Several new reduced-risk pesticides such as the fungicides fenhexamid (ELEVATE) and chitosan (ELEXA) are now available and being integrated into the relatively small family of pest management tools available to strawberry growers. Two more fungicides, SWITCH (cyprodinil and fludioxonil) and QUADRIS (azoxystrobin) are being registered Fall of 2001 in California and will be important additions to *Botrytis* and anthracnose resistance programs. Unfortunately, utility of SWITCH is limited by a crop rotation restriction which will not be removed for another two years. SAVEY (hexathiazox) achieved full registration in California in 2000 and is a critical and much needed element in the springtime miticide program. Imidacloprid (ADMIRE) is in its third year of use under a Section 18 for whitefly, a pest which has spread and become a statewide problem on strawberries.

More new chemistries are anticipated in 2002. Two new reduced-risk miticides, milbemectin and bifenazate, will add much needed tools to the mite resistance management program and will also offer an option for winter mite control that has not been available since the loss of propargite for fruiting fields. Registrations of imidicloprid (ADMIRE) for whitefly control, which has been under Section 18 use the last 3 years, and spinosad (SUCCESS) for thrips and worm control, are also anticipated in 2002.

New Active Ingredients Needed. While new materials have been registered since 1999, the industry still needs new pest management tools to replace materials already lost or modified beyond effective use on strawberries. An expedited registration for use on strawberries is strongly needed for new chemical pest management tools such as the following:

Spinosad (SUCCESS) is a new active ingredient product that is needed for control of western flower thrips, cutworms, beet armyworm and cabbage looper. Chlorfenapyr (ALERT) is needed for use on cutworms and beet armyworms, as well as mites. Methoxyfenozide (INTREPID) is an insect growth regulator needed for control beet armyworm, cutworm and cabbage looper. Pyriproxifen (ESTEEM) and thiamethoxam (PLATINUM) are new insecticides that are effective against whitefly. Etoxizole (BAROQUE) effectively controls spider mites without disrupting predatory mites. These products are needed for mite and insect control in California and resistance management.

Botrytis fruit rot and anthracnose are primary diseases of strawberries in California. Tebuconazole (ELITE) is needed for control of powdery mildew. These products are needed as soon as possible in California to control disease and to manage fungicide resistance.

Research Needs - Future Challenges. Research and development into alternate pest management systems that can substitute for the current uses of methyl bromide is clearly the number one future challenge and focus of the industry's research efforts. Methyl bromide use will be significantly reduced beginning in 2003 and will no longer be available for use in 2005. There are no comparable broad-spectrum tools available for control of soil-borne pests and diseases. Methyl bromide has been the key pest management tool for the California strawberry industry for several decades. The strawberry industry faces the challenge of developing sound, multi-faceted, reduced-risk approaches to try to fill the multiple voids that are anticipated with the removal of this single chemical tool.

Other areas of particular research needs are the development of control methods for western flower thrips, mites, and Lygus bugs. Lygus is of growing concern because no new effective chemistries for its control are in the pesticide pipeline. Lygus is difficult to control with the current few tools available, and damage thresholds are very low. If any single tool is lost, Lygus could become a very serious problem. Diseases of increasing concern to the industry include verticillium wilt and phytophthora crown and root rot though significant increases in the resistance of *Botrytis* fruit rot to existing fungicides has triggered increasing research into new pest management tools and expanded use of IPM use by the industry. Finally, development of weed control methods requires a rapid increase in research as methyl bromide has been the primary herbicide tool used by the industry.

PRODUCTION FACTS

- **California'sContribution to Production.** California produces more than 80% of the fresh market and processed strawberries grown in the United States on about 50% of the country's strawberry acreage. California produces about 20% of the world's production (1, 2, 7).

- **Exportation.** California exports about 20% of its strawberry production, accounting for 20% of the world's exported berries. California's primary export destinations are Canada, Japan, and Mexico (1).

- **Acreage.** Bearing strawberries are grown on approximately 22,000 to 25,000 acres per year in California (1, 2, 8, 10).

- **Production and Value.** As of 2001, average production in California was 1.3 billion pounds, with an estimated annual value of $600,000,000 (1, 8).

- **Fresh vs. Processed Markets.** 73% of the strawberry fruit produced are for fresh market and about 27% are for processing (1, 8).

- **Productivity per Acre.** California productivity per acre is over 4 times higher than the productivity in most other states. California produces 49,000 lbs/acre compared to an average of 11,600 lbs/acre for other states and a national average of 29,700 lbs/acre (7). California'sproductivity is twice that of the state with the second largest production, Florida, and ten times greater than New York production.

- **Cost per Acre.** The cost to produce an acre of strawberries/year amounts to $9,500 to $12,000 per acre, pre-harvest (8). The value per acre for harvested strawberries varies based on yield (trays/acre) and quality. Total costs per acre, including harvest costs which typically are $3.25 per tray of berries, range between $25,000 and $30,000 (1, 8).

- **Nursery Stock**. California nurseries supply almost 100 % of strawberry root stock used within California and a significant portion of the stock used as the foundation for strawberries in other states and countries. 1,000,000,000 plants are produced in California nurseries each year. California farmers use 600,000,000 plants annually and 400,000,000 plants are exported to other states, Canada, Europe and Asia (8). The value of this nursery stock is about $60,000,000.

- **Consumption.** Strawberry consumption is the fourth highest for fruits (8).

PRODUCTION REGIONS

Production Regions. California strawberry production occurs primarily along the central and southern coast, with a small but significant production occurring in the Central Valley. Fruit production can be divided into five different growing regions. The University has defined these regions as follows (6, 8):

1. **Central Coast Region**:
   Comprised of Watsonville, Salinas, Gilroy, Aromas and adjacent areas. Makes up 48% of the total strawberry production acreage.
2. **Santa Maria Region**:
   Comprised of San Luis Obispo, and northern Santa Barbara counties. Makes up 11% of the total strawberry production acreage.
3. **Oxnard Plain Region**:
   Comprised of Oxnard and Ventura County. Makes up 27% of the total strawberry production acreage.
4. **South Coast Region**:
   Comprised of Orange, Los Angeles, San Diego and western Riverside county. Makes up 10% of the total strawberry production acreage.
5. **Interior Valley Regions**:
   Comprised of interior valleys such as the central San Joaquin Valley (e.g., Fresno and Merced counties). Makes up about 3% of the total strawberry production acreage.

Nursery Production. Nursery stock are produced in two areas of the state, the Central Valley and in high elevation nurseries in Northeastern California. Central Valley nurseries are primarily located in the Northern San Joaquin Valley and Northern Sacramento Valley. High elevation locations are primarily in the state's Cascade mountain range (6, 8). The valley nurseries supply pest/disease free plantings to the high elevation nurseries, as well as other foreign and domestic nurseries.

Production Schedules by Region. Strawberries are harvested in one or more of the growing areas every month of the year, with peak production occurring from mid-April to mid-May. California strawberry yields are over 50% higher per acre than the national average yield and total yield for the industry is over 4-fold higher than the other states combined (7).

As discussed in this crop profile, the high production of strawberries in California can be attributed to a number of practices. Effective pest management techniques contribute significantly to the high productivity of the California strawberry industry. Among the other contributing factors are the high yield potential of the cultivars grown and the mild coastal climates ideal for strawberries. In addition, high yields are also the result of the use of annual production systems that use pathogen- and pest-free planting stock each year. Other contributors are the intensive management of the crop and rotation of one third of the state's acreage to alternate crops.

The high level of crop rotation (about 1/3 of the production acreage) and the high level of new plantings each year results in discrepancies in the statistical estimates of strawberry production per year (1, 2, 4, 7, 8). For example, the California Department of Pesticide Regulation's (CDPR) Pesticide Use Database (PUR) (4) often overestimates acreage about twice as large as the actual acreage in strawberry production in any given season. Annual berries are planted at the end of one year, for production the next year. The overestimate occurs because the large number of acres that are active during the bulk of one calendar year are added to the new acres planted at the end of the year for the next year's production. Accurate acres planted for each season are available (8), and are used with the CDPR PUR data to recalculate percent crop treated more accurately. For the years 1997-1999, total strawberry acreage was 22,508, 24,164, and 24,603 acres respectively.

CULTURAL PRACTICES

All of California's strawberry acreage is irrigated and most of the crop is grown on an annual basis. Strawberry plants for planting stock are initially grown in the state's nurseries for three to four years followed by transplantation during the summer or fall into grower's production fields. Strawberries are harvested during the following winter, spring, summer and fall. The plants are destroyed after the first harvest season and new plantings are established for subsequent crops. Strawberry plants produce fruit for six months or longer in California. To some extent, berries are picked every month of the year in some area of California.

Nursery Stock Use. California strawberry nurseries produce about 1,000,000,000 runner plants each year, with a farm gate value estimated at about $60,000,000. California is the world's leading producer of strawberry plants. As a result of climate, geography, modern nursery production and postharvest handling systems, and the Strawberry Certification Program administered by the California Department of Food and Agriculture, California nurseries produce high quality strawberry plants that are marketed to nursery and fruit growers throughout the United States and worldwide. Approximately 15% of production is marketed outside California. For plants sold out-of-state, about 40% are sold for nursery planting stock, and the remainder sold for fruit production purposes (8).

In California, commercial strawberry plant propagation is a multi-year process. Runner plants produced in one nursery propagation cycle are used as planting stock in the next cycle. The first runner generation is produced in a screen-house, followed by at least three additional runner generations produced in field nurseries. Two or more field propagation cycles occur in low-elevation (less than 500 ft elevation) nurseries in the state's interior valleys (primarily the Sacramento Valley) where climatic conditions result in prolific runner production during a long growing season. A final field propagation cycle occurs in high-elevation nurseries in northeastern California (at greater than 3,200 ft elevation), where temperature and photoperiodic conditions limit nursery runner production but result in increased transplant vigor, and increased productivity and fruit quality when the transplants are planted for berry production. Nursery location and nursery production practices effect transplant performance in California strawberry fruit production systems (11).

Nursery stock for summer-planted fields comes from low-elevation nurseries located in the Central Valley. These nursery fields are planted in the mid-Spring and harvested at the end of the calendar year. The resulting nursery stock are trimmed, packaged, and kept in cold storage until transplanting into fields the next summer. High-elevation nurseries are used for fall plantings. In these cases, harvested nursery stock are used immediately for transplanting into production fields.

Fumigation. Several weeks before planting, in all but the organically-grown acreage of the state, the soil is fumigated with a combination of methyl bromide and chloropicrin applied under a sealed plastic tarp (mulch), which is removed after 5 days. Methyl bromide alternatives are also beginning to be used including drip applied 1,3-dichloropropene, chloropicrin, and combinations thereof, and metam-sodium. For drip-applied materials and bed fumigation with methyl bromide, beds are preformed and tarped before the fumigation occurs. For flat fumigated land, after an appropriate plantback period, the ground is reworked, raised beds are formed, irrigation tape layed, and beds covered with the plastic mulch. Plants are set by hand into deep, narrow holes on pre-moistened, mulched beds. The plastic mulch stays in place until the plants are removed at the end of the season.

Mulch. Plastic mulch is used to ensure that the strawberries and plant foliage are separated from the ground. This reduces pathogen transfer, enhances soil warming and improves water management. The color of the tarp is important for efficacy and productivity. Typically, clear polyethylene mulch is used which is best for warming the soil and increasing early plant growth. In Southern California, use of black or colored tarps reduce weed populations but result in a 10% yield reduction due to less effective soil warming.

Harvesting. The grower/shipper or shipper assumes control of all operations related to harvest. Once harvesting commences, hand-harvesting continues for several months on a 3 to 5 day cycle for fresh berries and a 5 to 7 day cycle for processing berries. This continual harvesting ceases when the productivity of the field diminishes significantly. The Camarosa variety allows harvesting of fresh berries for the bulk of the season, followed by processing berries in the last couple months of harvest.

Fresh strawberries are harvested carefully by hand and are not subject to washing at the time of harvest or subsequent cooling. Processing berries are also carefully harvested and the calyx removed in the field with a harvesting tool. Processing berries are gently washed at the packing facility. Harvested strawberries are placed in trucks within an hour or two of picking and transported to the cooling facility. Strawberries are typically forced-air cooled at temperatures of 34°F one to four hours after harvest. Cooling reduces decay and prolongs the fruit shelf life.

Nearly all fresh strawberries are shipped in high nitrogen atmosphere to the market in refrigerated trucks, at temperatures in the range of 34-36°F during shipment. The following examples are provided to indicate typical times associated with the harvesting, cooling, and shipping operations:

Time After Harvest	Activity	
Day 1	Harvest. Delivery to yard and cooling (1-4 hours).	
Day 2-6	Shipping within the United States:	
	To Seattle	1 day
	To Denver	2 days
	To Chicago	3 days
	To New York/Boston	4 days

	Receiving dock to supermarket:	1 day
Day 2-6	Shipping outside the United States:	
	Canada	3-5 days
	Mexico	3-5 days
	Japan (air freight)	1 day

Varieties. Over a dozen major cultivars of strawberries are grown commercially in California. Strawberry cultivars are developed based on several factors including desired day length, fruit size, flavor, appearance, and vigor. Cultivars vary in their susceptibility to some pests and abiotic disorders. In 2001, the Camarosa strawberry variety was planted in 43% of the state's acreage, with the Diamante variety planted in 20% of the acreage. Proprietary varieties account for 29% of the acreage. Other varieties, for instance Chandler and Aromas, comprised 8% of the cultivars in 2001. Two new varieties developed by the University of California, Ventana and Camino Real, were released for the 2002 growing season (1, 8).

The primary cultivar grown in the central and southern coastal regions is the Camarosa, with this variety accounting for 98%, 55%, and 74% of the acreage in the Orange/San Diego, Oxnard, and Santa Maria districts, respectively in 2001. In contrast, Camarosa is only 14% of the Watsonville/Salinas district. The Diamante and proprietary varieties are primarily used in the Watsonville/Salinas district whereas the Chandler variety predominates in the San Joaquin Valley (1, 8). Other cultivars that are grown include the Seascape, Aromas, and Selva. Specific planting and harvest seasons vary from one growing area to another; however, two planting seasons are used in most areas. Summer plantings usually are made in mid to late summer and fall plantings from mid-October to early November. Summer plantings are grown in the San Joaquin Valley and Southern California.

Cultural Practices. Decisions related to various cultural practices are made daily by growers. Decisions related to field selection, soil nutrient supplements, and cultivars are made well in advance of planting. Fields are graded and planting beds designed to allow proper drainage and irrigation. Clean tillage, raised beds, plastic mulches and water management are all aspects of a systems approach practiced by California strawberry growers.

Crop Rotation. Strawberry fields are sometimes rotated with another cash crop such as beans, broccoli, lettuce, and cauliflower to reduce pest populations and improve soil structure. Time is allowed from one crop to another to allow crowns from the previous crop to decompose completely. Cover crops such as rye or barley, are also sometimes rotated but where land and water costs are high, cover crops are not economically feasible (6, 8).

Sanitary Techniques. Growers use high quality pathogen-free cultivar transplants and the Strawberry Certification Program sponsored by the California Department of Food and Agriculture to help maintain their field free of pathogens. The certification program is based on nursery soil treatment with methyl bromide prior to planting. Growers also practice field sanitation, working the "cleanest" (pathogen free) fields first, rinsing the equipment with hot water to remove soil and plant debris before working another field. Weeds are removed from and around strawberry fields before they produce seed. Growers also try to ensure that manure or other organic amendments added to the fields have been properly composted or sterilized (6).

Pesticide Application Practices. All applications of pesticides in California are under the control of the growers, and/or their Pest Control Adviser (PCA), or Pest Control Operator (PCO). Growers, PCAs, and PCOs work closely to insure that only registered pesticide products are used and that they are applied in compliance with all state and federal laws, rules and regulations, and labeled recommendations.

Communication between growers, PCAs, and PCOs is maintained during the planting and production periods through frequent field visitations by grower representatives and/or their PCAs. The applicator must inform all affected parties in close proximity to the intended treated area (e.g., harvesting crews, weeding crews, irrigators, etc.) of their intent to apply pesticides in advance of the application and must also post fields and file post-application paperwork with the appropriate state and/or federal agency. Closed systems are also mandatory for the application of Toxicity Category I pesticides in California.

Worker Activities. Fall planted berries are hand weeded approximately three times during the season, soon after planting, and again in January or March. Strawberries are all hand harvested, once a week from approximately January to March (depending on region) and then twice a week from March through approximately June. Picking crews generally work six days a week during this period. Processing berries, usually picked toward the end of the season are generally picked once a week. Irrigation, fertilization, and many pesticide applications are done through drip irrigation. Sprinkler irrigation is only done right after planting from October through Thanksgiving. Summer planted berries have similar regimes, with the addition of once or twice in the season crews going through to do runner cutting.

Worker activities related to soil fumigation are highly regulated by the State of California through restriction of worker hours depending upon activity, large buffer zones limiting access and activities near fumigation activities, and extensive restricted-entry intervals (5 days or more.) Worker exposure is reduced dramatically with the drip applied fumigants which are anticipated to become the method of choice eventually.

Virus Reduction. Because insect-vectored viruses are so devastating to strawberries, cultural methods have been changed radically to minimize the serious impact of these many viruses. All varieties are produced through a meristem program to remove viruses. Nursery production fields are far removed and isolated from strawberry fruit production regions. In most production regions, annual plantings are used to minimize virus impacts on fruit production, aphids are monitored and controlled when any virus is detected, and resistance management is practiced for insects, mites and fungal diseases.

Organic Production. Organically grown strawberry production is currently less than 0.1% of the total acreage. Reports on production yields per acre from organic fields range from 25% to 60% of the conventional yields (8).

PESTS OF CALIFORNIA STRAWBERRIES

General Comments on Pest Management Summaries

The following sections describe the cultural, biological, and chemical pest management tools that are used by California's strawberry industry to control specific pests. The discussions are presented on a pest-by-pest basis, with "insect" pests being listed first, followed by nematodes, diseases, weeds, and vertebrate pests. The following summaries are based, to a large extent, on the excellent summaries compiled and distributed by the University of California Integrated Pest Management Project. These guidelines were authored by many different specialists and farm advisors from the University of California's Cooperative Extension. We wish to acknowledge this contribution.

The following pest management summaries are also based on documentation from the UC-IPM Project, the UC Division of Agriculture and Natural Resources, California's Department of Pesticide Regulation, the California Department of Food and Agriculture and the California Strawberry Commission. The summaries are also based on extensive comments and suggestions from experts from the agricultural community. Their practical input has made the details within these summaries possible.

Use of DPR Pesticide Use Database.

Except where otherwise noted, the pesticide use data presented in the following summaries are based on the California Department of Pesticide Regulation's (CDPR) 1999 Pesticide Use Report (4). We have modified the percent of crop treated values reported by the CDPR. In determining the total acres planted in 1996, the DPR's data base added up all the separate acreage that reported at least one pesticide application in calendar year 1999. This calculated to be 47,372 acres (4). The California Strawberry Commission reports that 24,603 acres of strawberries were planted that same year (8). The discrepancy between the two figures is that the CDPR estimate does not account for the acreage that is planted at the end of one calendar year and harvested in the next. Since a significant portion of the acreage is rotated through other crops, the acreage is over estimated in the CDPR data base for strawberries. We have corrected the percent usage numbers by using 24,603 acres as the bases for these calculations (8).

Soil-Borne Pest Management and Methyl Bromide.

The following pest management summaries are presented on a pest-by-pest basis with the exception of methyl bromide. Methyl bromide is a broad spectrum soil fumigant used extensively by California's strawberry industry to control a wide variety of soil-borne pests. Methyl bromide in combination with chloropicrin is used to fumigate soils for production of all of California nursery stock, including planting stock intended for organic production, and essentially all of California's fruit production acreage. Only acreage used to produce organically grown fruit or part of grower trials to assess pest management strategies in the absence of methyl bromide are not fumigated with methyl bromide.

The methyl bromide/chloropicrin combination pre-plant fumigation has proven efficacious against a large number of diseases, arthropod pests, and weeds. It is very effective against diseases such as soil-borne fungi that cause verticillium wilt, Phytophthora root and crown rots, anthracnose, black root rot, charcoal rot, and, significantly, other soil-borne pathogens of unknown etiology that impact strawberry plant yield and quality. Methyl bromide/chloropicrin treatments are also effective for control of arthropods such as root weevils, cutworms, strawberry rootworm, white grubs, garden symphylan, and ground mealybug. The combination is also highly effective against nematodes such as foliar and root-knot nematodes and is one of the truly effective nematocides. Weed seeds of all species with rare exceptions such as field bindweed, little mallow, burclover, sweetclovers and filaree are also susceptible to methyl bromide/chloropicrin soil fumigation.

Research has shown that increased plant vigor due to methyl bromide/chloropicrin fumigation allows plants to withstand more intensive spider mite pressure with less yield reduction than is observed without this fumigation. The use of methyl bromide/chloropicrin provides early root development and plant vigor stimulated by the suppression of diseases in the soil and is a critical element in Integrated Pest Management strategies throughout the season. Methyl bromide pre-plant fumigation has been shown to double yields when no known pathogens or pests are present in the soil (12).

Methyl bromide was identified as an ozone depleter and as a result will be phased out of use by Developed Nations in the year 2005, and by Developing Nations in the year 2015 according to the Montreal Protocol. Extensive research on methyl bromide alternatives has been underway the last ten years. To date there are no broad-spectrum soil fumigant "drop in" alternatives comparable to methyl bromide that are currently available to the strawberry industry for widespread use. The drip applied Telone/chloropicrin product (InLine) comes closest of the currently registered materials, but suffers from restrictive township caps limiting its use in California. Work continues with combinations of chloropicrin, metam sodium and 1,3-D to develop alternative effective fumigation programs to replace methyl bromide/chloropicrin. Two new active ingredients, iodomethane and propargyl bromide may fully replace the wide-spectrum of control of methyl bromide, but they are years aware from registration and still require significant field efficacy research.

The use of methyl bromide as a key pest management tool has resulted in relative economic stability for the California strawberry industry for many years. With the impending loss of methyl bromide as a pest management tool, the strawberry industry faces additional challenges of further modifying the currently available, multi-faceted, reduced-risk approach to integrated pest management that provides viable biological controls, cultural practices and chemical tools for disease, insect and weed control. The continued economic success of the strawberry industry in California will be based, in part, on the industry's ability to develop a pest management program without methyl bromide that still balances sound cultural and biological control practices with chemical treatment.

New chemical tools tend to be more narrow than the broad spectrum pest control that methyl bromide provides. To replace methyl bromide soil fumigation, more narrow spectrum reduced-risk chemistries will be needed for each pest or disease currently controlled by soil fumigation. In addition, diseases and pests previously held down by years of methyl bromide fumigation may arise as new pests to strawberries requiring additional control measures. Enhanced use of cultural techniques such as mulching, solarization and plant breeding are also being studied. It is clear that, for California's strawberry industry, many different chemical and cultural tools will be needed in the near future to substitute for this single pest management ingredient.

The loss of methyl bromide will have a significant impact on many of the following discussions of pests, their severity, and the effectiveness of pest management tools to control their adverse effects.

PRIMARY ARTHROPOD PESTS

It is important to note that all discussions related to insect control are based on pest management strategies utilizing certified pest/disease free nursery stock growing in soil treated with methyl bromide/chloropicrin.

TWOSPOTTED SPIDER MITE
Tetranychus urticae

Damage. The twospotted spider mite is a serious pest of strawberries in all California growing areas. Twospotted spider mite damage to strawberries is expressed as stippling, scarring, and bronzing of the leaves and calyx. Twospotted spider mite feeding seriously interrupts photosynthesis and is particularly damaging during the first 4 to 5 months following transplanting, in late summer, fall, or early spring, depending on the growing region. Mite feeding during this critical period of plant growth substantially reduces berry numbers per plant and overall yield. Plants are less sensitive to mite feeding after initial berry set but yield loss can be significant at all mite infestation levels exceeding one mite per leaflet. Substantial yield loss can result from densities exceeding 5 to 10 mites per leaflets until mid-spring, and 20 mites per leaflet or more thereafter. Plants that sustain infestations of greater than 75 mites per leaflet may become severely weakened and appear stunted, dry, and reddish.

Description of Pest. Twospotted spider mites are typically found on the bottom surface of strawberry leaves. Mating and egg laying behaviors are typically observed in all coastal strawberry growing regions year round. The highest mite populations are often observed following the spring fruit harvest, and this peak is typically followed by a rapid, natural decline in mite density.

Monitoring. Growers monitor the twospotted spider mite pressure within the field to determine if they are being maintained below economically injurious levels. Vigorous plant growth during the first 4 to 6 months following fall transplant is a key factor in strawberry production. More than 80% of strawberry acreage is fall-planted and mite control during the first 4-6 months is critical when the effectiveness of many technologies (i.e. predators, AVID, VENDEX) is marginal. During this critical period, mite feeding is extremely damaging and the established economic threshold is five or fewer mites per mid-tier leaflet. *Tetranychus cinnabarinus* is a close relative of the twospotted spider mite and should be identified correctly. It is commonly found at low densities but has only been reported as damaging in San Joaquin Valley growing regions.

CONTROLS

Cultural

Vigorous Cultivars. Damage by twospotted spider mites is minimized by using cultural practices that favor vigorous plants. Strawberry cultivars vary in susceptibility to twospotted spider mite infestation and tolerance of twospotted spider mite feeding.

Chilling. Plants with insufficient amounts of chilling will have low vigor and will often develop intolerable mite infestations. Excessive chilling will promote increased vigor and reduce mite abundance, but other production factors are affected adversely (i.e., delayed flowering, large plant size, increased vegetative runner production).

Crop Rotation. Crop free periods can potentially reduce the rate at which spider mite populations become resistant to miticides.

Dust Reduction. Road dust control is important in inhibiting mite infestations, as dusty conditions favor the buildup and dispersal of twospotted spider mites.

Other Factors. Fall transplant, nursery location, preharvest chilling, nursery harvest date, and length of pretransplant supplemental cold storage can all affect a plant's productivity. Other controllable factors affecting plant vigor are soil preparation and fumigation, fertilization, and use of polyethylene plastic mulch and the color of the plastic.

Biological

Predator Mites. Biological control alone rarely provides control of spider mites sufficient to prevent yield loss. Biological control methods are typically used in conjunction with chemical pest management techniques, as chemical miticide treatments reduce strawberry yield loss due to spider mites about 4 times over fields relying strictly on predator control. In the Oxnard Plain region, for example, predator mite introductions typically follow applications of miticides such as hexythiazox (SAVEY). Predator mites such as *Phytoseiulus persimilis*, *Galendromus occidentalis*, and *Amblyseius californicus* are commercially available for release. Inoculative releases (i.e., initial releases of a small number of predators) are made when twospotted spider mites are first found in the field. Inoculative releases into hot spots within the field may also aid in suppressing infestations. Subsequent inundative releases of predaceous mites may also help to reduce twospotted spider mite infestations. Another predator mite, *Phytoseiulus macropilus*, occasionally occurs in strawberries early in spring. The success of predator mites is strongly influenced by meteorological factors, such as rainfall and temperature.

General Predators. Other natural enemies include minute pirate bugs (*Orius tristicolor*), a small black lady beetle (*Stethorus* spp.), a small black rove beetle (*Oligigota oviformis*), bigeyed bugs (*Geocoris* spp.), brown lacewing (*Hemerobius* spp.), green lacewing (*Chrysopa* spp.), sixspotted thrips (*Scolothrips sexmaculatus*), damsel bugs (*Nabis* spp.), and a cecidomyiid fly maggot (*Feltiella acarivora*).

Chemical (Currently Registered)

Twospotted spider mites have a history of developing resistance to miticides rapidly when a miticide is applied repeatedly to the same population. Alternating the use of miticides that have different modes of action helps reduce the development of resistance to a specific miticide. Organophosphate, carbamate, and pyrethroid insecticide applications can stimulate twospotted spider mite outbreaks by disrupting the balance with beneficial insects.

Critical, Most Used Pesticides.

Hexythiazox. 3 day PHI. Hexythiazox (SAVEY) was registered in 2000. The typical use rate is one application per season of 3 oz. ai/acre early in the season before introduction of predator mites. SAVEY is not allowed on strawberry nurseries. The restricted-entry interval for hexythiazox is 12 hours. In 2000, SAVEY was applied to approximately 62% of the strawberry acreage.

Avermectin. 3 day PHI. Avermectin (a.k.a., abamectin)(AGRI-MEK) is applied at a average rate of 0.02 lb ai per acre. In 2000 it was applied to about 67% of strawberry acreage, with an average of 2 applications per field annually. Avermectin is less effective under cold weather conditions. Two applications are made 7 to 10 days apart when mites reach detectable levels under warmer temperatures in late winter/spring. A maximum of 4 applications (two paired treatments) is permitted in a growing season. Avermectin is not registered for strawberry nurseries. The restricted- entry interval for avermectin is 12 hours.

Dicofol. 3 day PHI. Dicofol (KELTHANE) is an organochlorine applied usually once per season at an average rate of 1.2 lbs ai per acre. Dicofol use has been dropping from 1997 to 2000 and was applied to 6% of treated acres of strawberries in 2000. It is most widely used for spider mite control in the Central Valley production fields. Pest resistance to dicofol is widespread. Dicofol can be effective at controlling twospotted spider mites following an extended period of no use. Because this material is one of the few remaining miticides registered for use on and effective against cyclamen mite, it is typically not applied to control twospotted spider mites and is used sparingly for cyclamen mite control. Dicofol is toxic to predaceous mites but is relatively nontoxic to beneficial insects. Dicofol has a restricted-entry interval of 48 hours.

Narrow Range Oil. 0 day PHI. Narrow range oil is typically applied at a rate of 1-2% oil to less than 10% of strawberry acres. This material is used for low to moderate infestations. Higher pest pressure requires the use of a more effective miticide. Narrow range oils are not used from peak bloom through fruiting period or when temperatures exceed 75°F. Narrow range oils are often used in rotation with avermectin to help reduce avermectin resistance. There is a danger of phytotoxicity when oils are used. There is no restricted reentry period.

Lesser Used Pesticides

Fenbutatin-oxide. 1 day PHI. Fenbutatin-oxide (VENDEX) is applied at an average rate of 1.2 lbs ai per acre but its use has dropped to around 1% of strawberry acres as of 2000. It is primarily used in the Central Valley production fields. Most uses are a single application per season. Pest resistance to fenbutatin-oxide has been widely reported and persists within a population. Two applications can be effective but resistance again becomes prevalent in the surviving twospotted spider mite population. Fenbutatin-oxide works poorly under cool conditions. The restricted-entry interval for fenbutatin-oxide is 48 hours.

Rotenone. 0 day PHI. Rotenone, a naturally derived substance from cube root, is sometimes used for control of spider mites, but is less effective and more expensive than other available products. Rotenone was applied to about 4% of the acreage in 2000 at an average rate of 0.01 lb ai per acre. The product can be used by organic growers. Rotenone is extremely toxic to fish. There is a 12 hour restricted entry interval for rotenone.

Fenpropathrin. 2 day PHI. Although registered for use on twospotted spider mites, the synthetic pyrethroid fenpropathrin (DANITOL) is not typically used for its control. Lygus bugs should be the primary target pest for this material early in the season and impacts on the mite populations would be secondary to the targeted use against other pests. In fact, severe mite resurgence can occur following its use. There is concern that excessive use of synthetic pyrethroids, like fenpropathrin, may lead to the development of pest resistance in both spider mites and Lygus bugs. When applied, is is usual one application at 0.4 lb a.i./acre. The restricted reentry period for fenpropathrin is 24 hours.

Bifenthrin. 0 day PHI. The synthetic pyrethroid bifenthrin (BRIGADE) is not typically used for control of the twospotted spider mite. Lygus bugs should be the primary target pest for this material early in the season. There is concern that excessive use of synthetic pyrethroids, like fenpropathrin and bifenthrin, may lead to the development of pest resistance in both spider mites and Lygus bugs. Severe mite resurgence can occur following their use. Bifenthrin is a relatively new chemical tool available to California growers and is applied at a rate of 0.1-0.2 lbs ai/acre. The restricted reentry period is 24 hours.

Cinnamaldehyde. 0 day PHI. Cinnamaldehyde (VALERO) was recently registered for use against both spider mites and powdery mildew, however it is not always effective against mites. It is applied at 1-2 gallons/acre. Phytotoxicity on certain cultivars can be a problem and should be tested on small plots before major use. The REI is 4 hours.

Chemical (Unregistered Products)

The following active ingredients are not currently registered for use on strawberries but are needed tools as soon as possible. Expedited registrations are encouraged by the industry.

Bifenazate (ACRAMITE) is very effective with minimal impact on predatory mites with an anticipated Federal registration in 2002.

Milbemectin (MESA), while similar to avermectin chemically, appears to work against avermectin resistant mites. Federal registration is possible in late 2002.

Etoxizole (BAROQUE) effectively controls spider mites without disrupting predatory mites.

Pyridaben. Pyridaben (PYRAMITE) could be an effective tool for the strawberry industry against moderate mite populations. It is not as effective as avermectin or several yet to be registered product (bifenazate) against high mite population.

LYGUS BUGS

Lygus hesperus

Damage. Lygus bugs are one of the causes of irregularly-shaped, cat-faced strawberries. Lygus bugs damage fruit by puncturing individual seeds; this, in turn, stops development of the berry in the area surrounding the feeding site. Lygus bugs are a serious pest in central strawberry-growing areas (interior valleys, central coast, Oxnard up) where strawberries are typically grown through the summer. Lygus are rarely pests in southern California, where the fresh market berry harvest is generally complete by the end of May.

Description of Pest. Adult Lygus bugs are about 0.25 inch long. Immature forms of Lygus bugs are as damaging as adults. The larger nymphs (immature forms) are pale green and look somewhat like an aphid. They can be distinguished from aphids by their more rapid movements. Overwintered Lygus bugs lay eggs in weeds in January which hatch in March.

Monitoring. Monitoring fields for nymphs and adult Lygus bugs is critical in their control. There are two major monitoring periods for Lygus bugs in strawberries grown in central California. Infestations in southern California strawberry fields are rare. Early in the season, growers monitor for the first appearance of Lygus nymphs on weed hosts. Lygus bugs can be active all winter. Monitoring for adults begins in mid-April to detect when adults first appear in the field.

CONTROLS

Cultural

Weed Control. Successful management of Lygus bugs includes control of weed hosts during the winter months, monitoring for the appearance of Lygus nymphs on weed hosts. Weed control along roadways, ditches, and field borders helps prevent spring buildup of

Lygus bugs. Weed control is carried out in March and early April while Lygus are still nymphs. Once adults are present on weeds, they migrate into strawberries when the weeds are removed. Infestations by Lygus bugs may become more severe without preplant soil fumigation with methyl bromide since the weed populations are likely to increase.

Vacuuming. Growers experimented with suction devices (bug-vacs) to control Lygus bug with some success (reduction of adult populations by 75% and nymphs by 9-50%), but this is not a common cultural practice at this time. Damage from Lygus bugs occurs at such low populations that this technique did not adequately reduce damage to the crops. If Lygus bug population levels are moderate to heavy, overall damage to the crop is only reduced by 10% through vacuuming (9).

Biological

General Predators. Bigeyed bugs (*Geocoris)* are the most important natural enemy of Lygus bugs. They feed on eggs and young nymphs. Damsel bugs also feed on eggs and nymphs, and minute pirate bugs feed on Lygus eggs. None of these natural enemies; however, is successful in keeping Lygus from reaching damaging levels when there is a heavy migration of adults into strawberry fields when wild vegetation dries up in the spring.

Anaphes iole. A parasitic wasp, *Anaphes iole*, which attacks Lygus eggs, is available commercially and can be used for inoculative releases. It can reduce Lygus populations in strawberry fields, but because thresholds for this pest are very low, economically acceptable results have not been achieved.

Chemical (Currently Registered)

Chemical treatments are applied to control Lygus when they are at the most susceptible first and second instar nymph stages. Insecticides applied to later nymphal stages and adults are much less effective. Short residue insecticides do not control Lygus bugs, necessitating repeated applications. Insecticides of different mode of action should be rotated to prevent development of Lygus resistance.

Critical, Most Used Pesticides.

Malathion. 3 day PHI. Malathion is the most important treatment for Lygus immediately after hatching. This chemical works well in IPM programs. Malathion is only effective against the first 3 nymphal instars. Effective control requires multiple applications, as residual is short-lived. Very high levels of Lygus bug resistance to this material have been identified in some growing areas. Malathion is applied at an average rate of almost 2 lbs ai/acre to about 65% of strawberry acreage in 2000. Statewide, the number of repeat malathion applications per year is 4. The restricted-entry interval for malathion is 12 hours.

Fenpropathrin. 2 day PHI. Synthetic pyrethroids such as fenpropathrin (DANITOL) are best when used late in the season due, in part, to their disruption of beneficial insects and the resulting infestations from other pests, especially spider mites. Pyrethroids are the most effective materials currently registered for Lygus control in strawberries but the potential for the development of resistance to these insecticides is high. There is concern that excessive use of synthetic pyrethroids, like fenpropathrin , may lead to the development of insecticide resistance in both spider mites and Lygus bugs. In fact, resistance of Lygus to DANITOL has increased since 1996. Lygus bugs should be the primary target pest for this material. Fenpropathrin was applied at an average rate of 0.4 lb ai/acre onto 37% of strawberry acreage in 2000, with an average of 1 application per season although 2 applications/year are allowed. The restricted-entry interval for fenpropathrin is 24 hours.

Bifenthrin. 0 day PHI. Bifenthrin (BRIGADE) is a relatively new tool available to California strawberry growers and is applied at a rate of 0.04 to 0.2 lbs ai/acre. It was used on 22% of the strawberry acreage in 2000. Synthetic pyrethroids such as bifenthrin are best when used late in the season due, in part, to their disruption of beneficial insects and the resulting infestations from other pests, especially spider mites. Pyrethroids are the most effective materials currently registered for Lygus control in strawberries but the potential for the development of insecticide resistance is high. In fact, resistance of Lygus to BRIGADE has increased since 1996. Although this material can suppress spider mites, it should be used primarily to control Lygus. Use of bifenthrin is limited to 2 applications/year. Applications made early in the season can lead to severe spider mite outbreaks later in the season. The restricted-entry interval for bifenthrin is 24 hours.

Naled. 1 day PHI. Naled (DIBROM) is an organophosphate that is applied at rates of about 1 lb ai per acre. In tank mixes, naled can be used at lower rates, typically half the normal application rate. It was applied to 23% of the state's acreage in 2000. When used naled is typically applied once a year. Naled provides good late season control, but is not used when temperatures exceed 85°F due to plant phytotoxicity. Use is typically limited to regions where the end of the season is cool. The restricted-entry interval for naled is 48 hours.

Methomyl. 3 day PHI for fresh and 10 day PHI for processing strawberries. Methomyl (LANNATE) is a carbamate that is used to control Lygus bugs when populations are high and other treatments have not been successful. Average applications are about 0.9 lb ai per acre with an average of 1 application per season. Methomyl was applied to about 31% of strawberry acreage in 2000. There is a 48 hour restricted-entry interval for methomyl.

<u>Lesser Used Products</u>

Pyrethrin and Piperonyl Butoxide. 0 day PHI. This combination of pyrethrins and piperonyl butoxide (PYRENONE) is applied at label rates to strawberry fields. Though not as disruptive as the synthetic pyrethroids, late season applications are preferred. This combination was used on only 1% of strawberry acreage in 2000. This combination is variable in its effectiveness against Lygus bugs. The restricted-entry interval for pyrethrin and piperonyl butoxicide is 12 hours.

Insecticidal Soap. 0 day PHI. A single application of insecticidal soaps can reduce nymphal populations by about 50%, but have little effect on adults. It also kills about 50% of predatory mite eggs, but does not affect motile predators. There is no restricted entry interval.

Diazinon. 5 day PHI. Diazinon is applied to strawberry fields at a rate of 1-2 lb ai per acre an average of 1 application per year. It may injure mite predators, resulting in an increase of twospotted spider mites. Diazinon was used on 12% of strawberry acres in 2000 primarily for control of other pests. The restricted-entry interval following applications is 24 hours.

Chemical (Unregistered Products)

The following active ingredients are not currently registered for use on strawberries but are needed tools as soon as possible. Expedited registrations are encouraged by the industry. Few products are in the Agrichemical company pipelines to date with any real activity against Lygus. The ones that follow have some activity, but may not be full replacement products for the OPs and carbamate currently used for high infestations.

Thiamethoxam (ACTURA), similar in chemistry to imidacloprid, has shown some activity.

Lambda cyhalothrin (WARRIOR) is another pyrethroid but is not currently registered on strawberries.

CYCLAMEN MITE
Steneotarsonemus pallidus

Damage. The cyclamen mite is an important pest of central coast strawberries. It has become a less significant problem as fewer strawberry fields are retained for multiple season use due to the shift to annual plantings. Leaves heavily infested with cyclamen mites become severely stunted and crinkled, resulting in a compact leaf mass in the center of the plant. Feeding on flowers can cause them to wither and die. Fruit on infested plants is dwarfed, and the seeds stand out on the flesh of the berry. When uncontrolled, this mite can prevent plants from producing fruit.

Description of Pest. At low population densities, cyclamen mites are usually found along the midvein of young unfolded leaves and under the calyx of newly emerged flower buds; when populations increase, these mites can be found anywhere on nonexpanded plant tissue. Cyclamen mites are primarily pests in second year plantings and are not visible to the naked eye. Adult female cyclamen mites overwinter in the strawberry crown.

Monitoring. Growers monitor unfolding leaves to identify the presence of mites. When one cyclamen mite/10 leaves is identified chemical treatment is indicated.

CONTROLS

Cultural

Precautions in Transportation. Cyclamen mites can easily be transferred from one location to another by pickers, bees, birds, and equipment, including strawberry freezer trays. Cyclamen mite infested nursery plants can be a source of this pest in strawberry production areas. Growers should insist upon uninfested nursery stock. When nursery stock plants are known to be infested by cyclamen mites, they are treated in hot water at 100°F for 30 minutes before planting. Freezer trays are also dipped in hot water between fields. Fresh clothing for field workers is also recommended.

Crop Rotation. Second year plantings, particularly those in infested fields, should be avoided in problem areas (problem area locations are rotated through other crops). To slow the spread of infestations, infested plants are removed as soon as symptoms appear.

Dust Reduction. Road and field dust reduction can also be important in inhibiting mite infestation. Dusty plants are a more desirable habitat for these pests. Roads and adjacent areas can be watered down.

Biological

General Predators. Two natural predator mites of cyclamen mite are *Typhlodromus bellinus* and *Typhlodromus reticulatus*, but they often do not provide economic control and are easily disrupted by insecticides. The sixspotted thrips can be an important natural enemy since this thrips can feed on cyclamen mites when they become very prevalent.

Chemical (Registered Products)

To control cyclamen mites, a high rate of water per acre (300-500 gal) is necessary to soak the unfolded leaves and immature flower buds located in the crowns. Growers sometimes remove or treat infested hot spots by hand-sprayer to suppress infestations to avoid treating the entire field. In nurseries, early-season control before the plant canopy closes over is critical. Use of certified pest and disease free nursery stock is a key to control.

Critical, Most Used Pesticides

Avermectin. 3 day PHI. Avermectin (AGRI-MEK) is applied at an average rate of 0.02 lb ai/acre with sufficient water to soak the material into the crown of the plant. It was applied to 67% of strawberry acreage in 2000 (although it controls several important strawberry pests). Avermectin works poorly under cold weather conditions. Most fields have two applications per season. Avermectin is not registered for use in strawberry nurseries. The restricted-entry interval is 12 hours.

Dicofol. 3 day PHI. Dicofol (KELTHANE) is an organochlorine applied with a wetting agent at a rate of 3-4 lb ai/acre in 400-600 gallons of water to soak the material into the crown of the plant. Dicofol was applied to 6% of strawberry acreage in 2000 with an average of 1 application per season and is very effective against cyclamen mite. Dicofol is toxic to predaceous mites but is relatively nontoxic to beneficial insects. The restricted-entry interval is 48 hours.

Diazinon. 5 day PHI. Diazinon is an organophosphate that is applied to strawberry fields at an average rate of about 0.5 lb ai per acre with an average of 1 application per year. It may injure mite predators, resulting in an increase in pest mites. Diazinon was used to treat about 12% of strawberry acres in 2000. The restricted-entry interval following applications is 24 hours.

Hexythiazox. 3 day PHI. Hexythiazox (SAVEY) was registered in 2000. The typical use rate is one application per season of 3 oz. ai/acre early in the season before introduction of predator mites. SAVEY is not allowed on strawberry nurseries. The restricted-entry interval for hexythiazox is 12 hours. In 2000, SAVEY was applied to approximately 62% of the strawberry acreage.

Lesser Used Pesticides

Carbaryl. 7 day PHI. Carbaryl (SEVIN) is a broad-spectrum carbamate applied to strawberry beds around the base of the plants at a rate of 2 lb ai/acre. The product can be harsh on beneficials and result in spider mite outbreaks. Carbaryl was applied to 28% of strawberry acres in 2000 while material was still available at the 1 day PHI. Use will be much reduced in future years because of the 7 day PHI. The restricted-entry interval for carbaryl is 12 hours.

Endosulfan. 4 day PHI. Endosulfan (THIODAN) is an organochlorine applied at a rate of about 1 lb ai/acre in 400 to 600 gallons of water to soak the material into the crown of the plant. Endosulfan has has decreased since 1997 to less than 1% of strawberry acreage because of the environmental restrictions. Reapplications are not made within 35 days. Single applications per year are the norm with no more than 2 applications being performed on any field, even though 3 applications per year are allowed. The restricted-entry interval for endosulfan is 24 hours.

Chemical (Unregistered Products)

The following active ingredients are not currently registered for use on strawberries but are needed tools as soon as possible. Expedited registrations are encouraged by the industry.

Bifenazate (ACRAMITE) is very effective with minimal impact on predatory mites with an anticipated Federal registration in 2002.

Milbemectin (MESA), while similar to avermectin chemically, appears to work against avermectin resistant mites. Federal registration is possible in late 2002.

Etoxizole (BAROQUE) effectively controls spider mites without disrupting predatory mites.

Pyridaben. Pyridaben (PYRAMITE) could be an effective tool for the strawberry industry against moderate mite populations. It is not as effective as avermectin or several yet to be registered product (bifenazate) against high mite population.

APHIDS

Strawberry Aphid: *Chaetosiphon fragaefolii*
Melon Aphid: *Aphis gossypii*
Green Peach Aphid: *Myzus persicae*
Potato Aphid: *Macrosiphum euphorbiae*

Damage. Aphid damage to berries occurs in all growing regions. Aphid damage is less critical in the central coastal region where aphid populations typically are not as high. Aphids occasionally cause yield losses in California strawberries because of their honeydew production. Honeydew deposits on fruit cause sooty molds to develop and the white skins shed by aphid nymphs to stick to the fruit. This contamination renders the fruit unmarketable as fresh fruit. Also, aphids transmit several viruses that can cause significant economic losses in perennial strawberries. Aphid control is also crucial in strawberry nurseries to reduce the possibility of virus transmission.

Description of Pest. Populations of aphids usually begin to reach potentially damaging levels in California during late January or February. Populations undergo a natural decline, usually to non-economic levels, during May and June. Strawberry aphid, typically the most common species of aphid found on strawberries, is pale green to yellowish in color. The melon aphid, the second most common species on strawberry, is often the first to migrate into the strawberry fields each season. Green peach aphid and potato aphid rarely account for more than 10% of the total aphid populations in the field. The potato aphid is much larger than the other species and has both a pink form and a green form in California.

Monitoring. Growers measure the percent aphid infestation by sampling trifoliate leaves. If infestation reaches a threshold, chemical treatment becomes necessary to minimize economic losses.

CONTROLS

Cultural

Plastic Covers. Some row covers (plastic tunnels or Remay-type enclosures) have reduced aphid populations to below economic levels. The cost of row covers are substantial and the economic viability for large- or small-scale plantings has not been established.

Dust Reduction. Road and field dust reduction can also be important in inhibiting aphid infestation. Dusty plants are a more desirable habitat for these pests. Roads and adjacent areas can be watered down. Controlling dust is important to facilitate parasite and predator activity.

Biological

Parasites and Predators. Natural enemies of aphids include parasitic wasps, *Lysiphlebus testaceipes, Aphidius, Aphelinu*; fungal disease; *Entomophthora*; lacewings; bigeyed bugs, minute pirate bugs, dustywings (*Coniopterygidae*); damsel bugs; and ladybugs. In some circumstances the levels of biological control can be economically viable, such as with the case of the melon aphid in southern California strawberry-growing regions.

Chemical (Registered Products)

Chemical treatments are made when aphid pest pressure reaches a trigger level (sometimes this trigger is when 30% of young trifoliated leaves are infected). Trigger levels can be selected to minimize the impact on beneficial insects in the fields.

Critical, Most Used Pesticides

Malathion. 3 day PHI. Malathion is another treatment for aphids though not as commonly used for this pest as diazinon. This chemical works well in IPM programs. Effective control requires multiple applications, as residual is short-lived. Statewide, the number of repeat malathion applications per year is 4, but these applications often target Lygus bugs. Very high levels of resistance to this material have been identified in some growing areas. Malathion was applied at a rate of 1 lbs ai per acre to about 65% of strawberry acreage in 2000. The restricted-entry interval for malathion is 12 hours.

Diazinon. 5 days PHI. Diazinon is the most desirable chemical treatment for aphids on strawberries. Diazinon is applied at an average rate of about 0.5 lb ai/acre an average of 1 application per season though multiple applications are allowed. Diazinon was used to treat 12% of strawberry acreage in 2000. It provides longer residual activity than soap. It may injure mite predators, resulting in an increase of twospotted spider mites. The restricted-entry interval for diazinon is 24 hours.

Naled. 1 day PHI. Naled (DIBROM) is an organophosphate that is applied at rates of about 1 lb ai per acre. It was applied to about 23% of the state's acreage in 2000. When used naled is typically applied once a year. Naled provides good late season aphid control but is not used when temperatures exceed 85°F due to plant phytotoxicity. Naled is typically limited to regions where the end of the season is cool. The restricted-entry interval for naled is 48 hours.

Insecticidal Soap. 0 day PHI. Insecticidal soaps are applied at rates of about 5.5 lb ai/acre, depending on the soap used. Insecticidal soaps are applied to approximately 10% of strawberry acres. No more than 2 applications/season are typically made because phytotoxicity may occur to the plants. Typically, a single application is made per season. In addition to aphids, these treatments also kill about 50% of predatory mite eggs, but does not affect motile mites. There is no restricted reentry period.

Chemical (Unregistered Products)

New chemistries are needed for aphid control because the primary products are all organophosphate insecticides vulnerable to FQPA and worker exposure issues. While methomyl, bifenthrin and fenpropathrin also have aphid acitivity, they are usually reserved for other pest control. The following active ingredients are not currently registered for use on strawberries but are needed tools as soon as possible. Expedited registrations are encouraged by the industry.

Imidacloprid (ADMIRE) is currently under Section 18 registration for whiteflies, but also has activity against aphids.

Thiamethoxam (ACTURA) is similar chemistry as ADMIRE with aphid activity.

ROOT WEEVILS

Cribrate Weevil: *Otiorhynchus cribricollis*
Woods Weevil: *Nemocestes incomptus*
Black Vine Weevil: *Otiorhynchus sulcatus*
Fuller Rose Weevil: *Pantomorus cervinus*

Damage. Root weevil larvae feed on the roots of strawberry plants and can completely devour small rootlets and destroy the bark and cortex of larger roots. Soon after feeding begins, plants wilt because the roots can no longer provide moisture for leaves. It is not uncommon to find weevil larvae that have penetrated into the lower portion of the plant's crown. These pests caused major economic damage in the 1950s prior to the onset of methyl bromide use. As a result, root weevils are anticipated to become an increasingly important pest in the next few years as methyl bromide is removed from the marketplace.

Description of Pest. Adult root weevils are beetles. They feed at night and hide around the crowns of plants during the day; they cannot fly. Adults feed on foliage and remove large scallops from the leaves. Such leaf damage is a good indication that weevils are present, but is not economically damaging to the plants. The adults, nearly all females, emerge in late spring or summer and feed on strawberry foliage. Eggs laid on the plants, after hatching, work their way into the soil and feed on strawberry roots and crowns. In spring, they resume feeding and can cause extensive damage before they pupate. Root weevils have a single generation each year.

Monitoring. Observations for infestation such as crown damage. Though some damage is acceptable, severe damage triggers control methods.

CONTROLS

Cultural

Crop Rotation. Annual plantings reduce the likelihood of high populations building up in fields. Crop rotation with non-host cover or cash crops may also help to reduce infestations.

Sticky Barriers. Sticky barriers are used to prevent movement of adult weevils from infested second year berries and host areas to newly fumigated plantings. Adult weevils overwinter in nearby native plants, ornamentals, blackberries or in second-year strawberries.

Weed-Host Control. Control of host plants adjacent to fields helps to reduce the potential for infestation.

Biological

No known biological controls of root weevils.

Chemical.

Soil Fumigation - General. Soil fumigation with methyl bromide and chloropicrin for weed and disease control has greatly reduced the presence and effect of root weevils. Prior to the use of methyl bromide, root weevils were a major economic pest of strawberries. Currently, root weevils require management only in a few central coast locations. However, with the impending loss of methyl bromide as a soil fumigant, it may be anticipated that root weevil management throughout the growing regions will increase. None of the currently registered chemicals will control these weevil larvae.

Methyl Bromide/Chloropicrin. 0 day PHI. Methyl Bromide with chloropicrin is applied as a preplant application, approximately 30 days prior to planting, to fields at a rate of 300 to 400 lbs ai combination/acre. It is applied to essentially all of the conventionally grown strawberry fields in California for control of pathogenic fungi, weeds, and nematodes. Methyl bromide is a restricted use material that may only be applied by permit from the county agricultural commissioner. Many use restrictions apply. The restricted entry interval for methyl bromide is 48 hours.

For the following non-fumigant treatments, large application rates and ample water are needed to ensure penetration into the soil-based habitats of root weevils.

Diazinon. 5 days PHI. Diazinon is applied to strawberry fields at an average rate of about 0.9 lb ai/acre. Rates used to control root weevil are typically higher to maintain adequate dosage because high volume applications are necessary to penetrate soil. It is registered for use on strawberries to control root weevils but is not very effective compared to the fumigants. It may injure mite predators, resulting in an increase of twospotted spider mites. Diazinon was used to treat approximately 12% of strawberry acreage in 2000. The restricted-entry interval for diazinon is 24 hours.

Bifenthrin. 0 day PHI. Bifenthrin (BRIGADE) is a relatively new chemical tool available to California strawberry growers and is applied at a rate of 0.05 to 0.2 lbs ai/acre to control root weevil. Synthetic pyrethroids such as bifenthrin are best when used at or near the end of the season due, in part, to their disruption of beneficial insects and predatory mites and the resulting infestations from other pests. This may not be the optimal treatment timing to achieve control. High application rates are needed to impact root weevil damage. For control, bifenthrin applications must be made early in the development of the weevil infestation. Although this material can impact root weevils, it is used primarily to control lygus. Use of bifenthrin is limited to 2 applications/year. The restricted-entry period for bifenthrin is 12 hours.

Methomyl. 3 day PHI for fresh and 10 day PHI for processing strawberries. Methomyl (LANNATE) is a carbamate that can be used to control root weevils when populations are anticipated to be high. Average methomyl applications are about 0.9 lb ai per acre with an average of 1 application per season. Application rates to control root weevils need to be higher than 0.8 lbs ai/acre. Methomyl was applied to about 31% of strawberry acreage in 2000, primarily for the control of Lygus bugs and for caterpillar control. The restricted entry interval for methomyl is 48 hours.

Chlorpyrifos. 21 day PHI. Chlorpyrifos (LORSBAN) is a broad-spectrum insecticidal organophosphate applied at an average rate of about 0.5 lb ai/acre to 13 % of strawberry acreage in 2000 though applications of this insecticide are targeted toward many pests, not just root weevil. Higher application rates are typically needed to control root weevils. Chlorpyrifos is critical for weevil control in southern California. The restricted-entry interval for chlorpyrifos is 24 hours.

WESTERN FLOWER THRIPS
Frankliniella occidentalis

Damage. Damage from thrips has increased in recent years. Damage, which rarely became economically significant in past years, is impacting yield and quality. When very abundant, more than 10 thrips per blossom, fruit can be seriously discolored (bronzed). Thrips feeding on strawberry blossoms causes the stigmas and anthers to turn brown and wither prematurely, though not before fertilization has occurred. As fruit develops, thrips feeding may cause a russeting of the fruit around the cap, but this type of injury is seldom economic.

Description of Pest. Western flower thrips are slender, very small insects. Flower thrips populations build up on alfalfa, weeds, and other vegetation in spring, and then move from these hosts when they are cut or dry up.

Monitoring. Control is necessary when western flower thrips are very high (typically a trigger of 10 thrips per flower).

CONTROLS

Cultural

Weed Control. Weed and vegetation management adjacent to berry fields helps to reduce thrips populations. Growers monitor for thrips by randomly collecting flower blossoms into a glass container with several drops of an insect-killing material soaked into cotton and then by counting the thrips.

Biological

Predators. Minute pirate bugs feed on thrips. It should be noted that thrips have been observed feeding on twospotted spider and cyclamen mites.

Chemical (Currently Registered Products)

Chemical control methods are only necessary when thrips become very high.

Methomyl. 3 day PHI for fresh strawberries. 10 day PHI for processing strawberries. Methomyl (LANNATE) may be applied at a rate of 0.45 – 0.9 lb ai per acre. Methomyl was applied to 31% of strawberry acreage though this product is used to manage many other strawberry pests and not typically thrips, unless pressure is very high. This percentage covers several pests that methomyl is used to control. The restricted-entry interval for methomyl is 48 hours.

Naled. 1 day PHI. Naled (DIBROM) is an organophosphate that is applied at rates of about 1 lb ai per acre. It was applied to about 23% of the state's acreage in 2000. When used naled is typically applied once a year. Naled provides good late season aphid control but is not used when temperatures exceed 85°F due to plant phytotoxicity. Naled is typically limited to regions where the end of the season is cool. The restricted-entry interval for naled is 48 hours.

Pyrethrin and Piperonyl Butoxide. 0 day PHI. This combination of pyrethrins and piperonyl butoxide (PYRENONE) is applied at label rates to strawberry fields. Though not as disruptive as the synthetic pyrethroids, late season applications are preferred. This combination is variable in its effectiveness. The restricted-entry interval for pyrethrin and piperonyl butoxide is 12 hours.

Chemical (Unregistered Products)

The following active ingredient is not currently registered for use on strawberries but is a needed tool as soon as possible.

Spinosad. This new active ingredient has good acitivity against thrips with registration on strawberries anticipated in early 2002.

Imidacloprid (ADMIRE) is currently under Section 18 registration for whiteflies, but also has activity against thrips with full registration anticipated in 2003.

Thiamethoxam (ACTURA) is similar chemistry as ADMIRE with thrips activity.

Pyridaben. Pyridaben (PYRAMITE) could be an effective tool for the strawberry industry against thrips.

CUTWORMS

Black Cutworm: *Agrotis ipsilon*
Roughskinned Cutworm: *Athetis mindara*

Damage. At times serious damage can occur to the plant crown. On fruit, during harvest, cutworms can cause pronounced holes. Early-season damage by newly hatched cutworms generally appears as small, webless perforations in the newly expanding crown leaves. As larvae grow, they begin their characteristic stem cutting along with chewing larger, irregular holes in the foliage. Damage by cutworms tends to be more serious in fields where bug-vacs have been used, but the reasons for this are not known and bug-vacs are rarely used.

Description of Pest. The black cutworm, also called the greasy cutworm, is the primary cutworm pest of strawberries in most growing areas but other species are found in damaging numbers on occasion. Most damage occurs in fall and spring, with the fall attack being more destructive. Migration of adult moths can also occur following harvest of other hosts, such as lettuce, in nearby fields.

Monitoring. Monitoring for cutworms is done visually or by trapping. Damage to fruit particularly is monitored.

CONTROLS

Cultural

Weed Control. Weed control is paramount to preventing a serious cutworm problem. Weedy fields tend to attract more moths to lay their eggs.

Vacuuming. This control is no longer used because vacuuming of small insects adversely impacts the control of cutworms (9).

Biological

Birds. Though birds can feed on cutworms and are the only known biological control, there is no evidence that this results in significant control and, of course, many of the same birds are serious pests to strawberries.

Chemical (Registered Products)

Baits. Baits (primarily carbaryl bait) are applied as soon as evidence of substantial leaf and/or stem cutting is noted. Bait applications are also made immediately after weeding, when cutworms have been found in order to prevent migration to the crop plants. There is no specific threshold for treatment.

Critical, Most Used Pesticides

Carbaryl. 7 day PHI for bait. Carbaryl (SEVIN) is a broad-spectrum carbamate applied as a bait or a spray to strawberry beds around the base of the plants at an average rate of 1.6 lb ai/acre. It is most effective if applied at night when cutworms are more active. Carbaryl bait is very important for control of cutworm but unfortunately has become less useful with the 7 day PHI. Unlike carbaryl broadcast sprays, bait applications are not harmful to beneficials. Carbaryl was applied to approximately 28% of strawberry acres in 2000 though this overall use is targeted towards several different pests. The restricted-entry interval for carbaryl is 12 hours.

Bacillus thuringiensis. 0 days PHI. *Bacillus thuringiensis* (Bt) is applied at label rates to a large amount of strawberry acres (totals are difficult to determine because each Bt strain is reported as a separate pesticide, averaging approximately 20%). Good coverage at relatively low dilution rates is essential to product performance though this performance is typically quite low against cutworms. Multiple applications are required. Treatments are made when young larvae are present. Some Bt are acceptable for use on organically grown produce. There is a 4 hour restricted-entry interval for Bt.

Chloropicrin. Chloropicrin as a pre-plant soil treatment, which is typically applied in combination with methyl bromide, can sometimes be effective in control of cutworms from previous crops. This combination of fumigants is used for preplant control of pathogenic fungi, weeds, nematodes, and soil borne insects, but can impact cutworm populations. The use of these chemicals in combination is being phased out. The use of chloropicrin alone may be effective against cutworm.

Chlorpyrifos. 21 day PHI. Chlorpyrifos (LORSBAN) is a broad-spectrum insecticidal organophosphate that may be used for cutworm control. It is applied at an average rate of 1 lb ai/acre to approximately 13-30 % of strawberry fields for control of many pests, not just cutworm. Chlorpyrifos is an effective tool in the control of cutworm shortly after planting and is critical to production in southern California, Santa Maria area and Ventura County. It provides economic control but kills beneficial and nontarget organisms. The restricted-entry interval is 24 hours.

Methomyl. 3 day PHI for fresh and 10 day PHI for processing strawberries. Methomyl (LANNATE) is a carbamate that can be used to control cutworms when populations are high. Average applications are about 0.9 lb ai per acre with an average of 1 application per season.

Methomyl was applied to about 31% of strawberry acreage in 2000. There is a 48 hour restricted-entry interval for methomyl.

Chemicals (Unregistered Products)

The following active ingredients are not currently registered for use on strawberries but are needed tools as soon as possible. Expedited registrations are encouraged by the industry.

Spinosad. This new active ingredient is not currently registered for use on strawberries but may be in the future.

Methoxyfenozide. This new insect growth regulator (INTREPID) is not currently registered for use on strawberries but could be an important tool for the strawberry industry.

Chlorfenapyr. Chlorfenapyr (ALERT) is not currently registered for use on strawberries but could be an important tool for the strawberry industry.

BEET ARMYWORM

Spodoptera exigua

Damage. The greatest damage from beet armyworm occurs to summer and fall-planted strawberries in the southern growing regions of the state. Newly hatched beet armyworms are foliage feeders, skeletonizing the upper or lower leaf surfaces adjacent to their egg mass. Larger larvae can attack the crowns of young plants, killing them. Young larvae feed on foliage before attacking berries. Larger armyworms feed directly into the berries. Smaller armyworms will often feed on the shoulder of the berry.

Description of Pest. Fall populations of armyworm moths will often fly into strawberry fields to lay eggs. Newly hatched armyworms are often green in color and feed in groups, skeletonizing the undersides of leaves.

Monitoring. Treatments are made while armyworms are still young. If large numbers of predators are present, treatments may be delayed to determine if the armyworms might be controlled by the natural enemies.

CONTROLS

Cultural

Weed Control. Growers control weeds in and near the field to minimize armyworm populations, as adult moths are attracted to weeds for egg laying.

Biological

Hyposoter exiguae. Young beet armyworms can be heavily parasitized by the ichneumonid parasite, *Hyposoter exiguae*. This parasite is easily monitored in the armyworm populations by simply pulling young worms apart and looking for the parasite larva inside.

Natural Virus. Armyworms often become diseased with a virus that can cause high mortality. High natural mortality translates to few mature larvae surviving to cause further damage.

Chemical (Registered Products)

***Bacillus Thuringiensis*, (principally subsp. aizawai and kurstaki).** 0 day PHI. *Bacillus thuringiensis* (Bt) is applied at rates of 0.1 lb ai/acre and is the best subspecies for controlling beet armyworm. A large amount of strawberry acres (totals are difficult to determine because each Bt strain is reported as a separate pesticide) are treated with Bt.. Good coverage at relatively low dilution rates is essential to product performance. Bt treatments are made when armyworms are still small. For Bt to be effective it must be applied no later than the second instar. Most Bt are acceptable for use on organically grown produce. There is a 4 hour restricted-entry interval for Bt.

Methomyl. 3 day PHI for fresh strawberries. 10 day PHI for processing strawberries. Methomyl (LANNATE) is a carbamate used to control armyworm when populations are high or when most of the larvae present are large. This insecticide can disrupt natural enemies of spider mites and other insects. The average application rate for methomyl is 0.9 lb ai per acre with typically one application being made per year even though multiple applications per season are allowed. Methomyl was applied to about 31% strawberry acreage in 2000. The restricted-entry interval for methomyl is 48 hours.

Pyrethroids. Synthetic pyrethroids (such as fenpropathrin and bifenthrin) can be used to control beet armyworms but these chemicals are harsh and impact beneficial organisms, often resulting in pest outbursts. These chemicals, if used, are used as cleanup.

Chemicals (Unregistered Products)

The following active ingredients are not currently registered for use on strawberries but are needed tools as soon as possible. Expedited registrations are encouraged by the industry.

Spinosad. This new active ingredient is not currently registered for use on strawberries but may be in the future.

Methoxyfenozide. This new insect growth regulator (INTREPID) is not currently registered for use on strawberries but could be an important tool for the strawberry industry.

Chlorfenapyr. Chlorfenapyr (ALERT) is not currently registered for use on strawberries but could be an important tool for the strawberry industry.

WHITEFLIES
Iris Whitefly: *Aleyrodes spiroeoides*
Strawberry Whitefly: *Trialeurodes packard*
Greenhouse Whitefly: *Trialeurodes vaporariorum*

Damage. Whiteflies have always been present in low numbers in strawberry fields on the central coast. The species that are present include the iris whitefly, *Aleyrodes spiraeoides*, and, to a lesser extent, the strawberry whitefly, *Trialeurodes packardi.* Populations of these species are usually kept below damaging levels by naturally occurring beneficial insects. In recent years, populations of a third species, the greenhouse whitefly, *Trialeurodes vaporariorum*, have been observed in increasing numbers in certain restricted areas in most of the strawberry growing areas. Like strawberry aphids, whiteflies suck plant juices and at high population levels can excrete large amounts of honeydew on which a sooty mold fungus grows. Whiteflies do not carry and transmit viruses of strawberry.

Description of Pest. Adult whiteflies are small insects. Whiteflies generally overwinter in the immature stage on the leaves of strawberries. Adults begin laying eggs on the undersides of leaves. Due to the relatively short life cycle of 4 to 5 weeks, there are several overlapping generations during the year.

Monitoring. Treatments are rarely necessary except along dusty road edges or if whitefly biological controls are disrupted by the use of a non-selective pesticide. Treatment is only necessary when honeydew becomes apparent, as has occurred more recently in the past few years.

CONTROL

Cultural

Topping. For summer-planted strawberries, the practice of topping in spring helps to reduce overwintering immature populations.

Dust Reduction. Growers minimize dust by keeping field roads watered or oiled allowing biological control to work effectively. Dust minimization helps in the control of mites and aphids also.

Vacuuming. The use of vacuuming small insects such as whiteflies is no longer practiced because the control was minimal and increases in secondary pests were aggravated (9).

Biological

Parasites and Predators. Numerous parasites and predators (e.g., *Prospetella, Encarsis*) generally hold down whitefly populations to the extent that damaging populations rarely occur. General predators include lacewings, bigeyed bugs (*Geocoris* spp.), and minute pirate bugs (*Anthocoris*). Use of harsh insecticides should be avoided where whitefly management is important.

Chemical (Registered Products)

Critical, Most Used Pesticides

Imidacloprid. 14 day PHI. Imidacloprid (ADMIRE) can be used under an Emergency Registration (Section 18) in California. The ingredient is an effective agent against whiteflies and relatively non-disruptive of the biological balance that is important in control of whiteflies. Admire can be applied once in a season through drip irrigation. For it to be effective, it has to be applied as a preventative treatment before whitefly populations have an opportunity to build to high levels. The root zone of the plant has to be well saturated and it will help to have the plant actively growing so that the plant will more easily take up the material. The restricted-entry interval for imidacloprid is 12 hours.

Avermectin. 3 day PHI. Avermectin (a.k.a., abamectin)(AGRI-MEK) provides a fair control of whiteflies. It is applied at a average rate of 0.02 lb ai per acre and in 2000 was appliedto 67% of strawberry acreage in California primarily for control of spider mites. Up to 4 applications per field are allowed annually. Avermectin works poorly under cold weather conditions. Avermectin is not registered for use in strawberry nurseries. The restricted-entry interval for avermectin is 12 hours.

Insecticidal Soap. 0 day PHI. Insecticidal soap is occasionally used to control whitefly. Applications are made when it is cool to avoid burning plants and may be made once a month or twice per season.

Lesser Used Pesticides

Pyrethroids. Use of synthetic pyrethroids have been implicated as the cause of some whitefly infestations. However, in outbreak situations they also provide some control of whiteflies. They can be tank-mixed with other insecticides, such as diazinon, to improve efficacy.

Chemicals (Unregistered Products)

The following active ingredients are not currently registered for strawberries but are needed tools as soon as possible. An expedited registration is encouraged by the industry.

Thiamethoxam (PLATINUM) is not registered for use on strawberries and is similar chemistry to ADMIRE with similar efficacy against whitfly.

Pyridaben. Pyridaben (PYRAMITE) is not currently registered for use on strawberries but it is needed as soon as possible for the control of whitefly. This material controls whiteflies without disrupting the beneficial organisms.

Buprofezin (APPLAUD) is also not registered for use on strawberries.

Pyriproxifen. Pyriproxifen (ESTEEM) is an insect growth regulator that is needed to complete the control program for whitefly.

SECONDARY ARTHROPOD PESTS

It is important to note that all discussions related to insect control are based on pest management strategies utilizing certified pest/disease free nursery stock growing in soil treated with methyl bromide/chloropicrin.

CABBAGE LOOPER
Trichoplusia ni

Damage. Young cabbage looper larvae feed primarily on the undersides of leaves, skeletonizing them. High populations can damage fruit but this is very uncommon. The cabbage looper is becoming more a pest challenge in the southern growing regions.

Description of Pest. Loopers have a characteristic arch to their back as they crawl. Eggs are similar in appearance to corn earworm eggs, but flatter.

Monitoring. When monitoring for other pests, growers watch for evidence of looper feeding: leaflets with holes, feces, and caterpillars feeding at the edge of a hole. If larvae are larger instars, an organophosphate may be needed to control them.

CONTROLS

Cultural

Placement of Fields Relative to Other Crops. Cabbage looper has only recently become a pest in strawberries planted next to lettuce fields. Selecting a strawberry field that is not adjacent to a host crop for cabbage looper is one way to control infestations, although this practice has become less practical due to rotation with vegetable growers.

Biological

Parasitic Wasps. Loopers are sometimes controlled by the parasitic wasps *Hyposoter exiguae, Copidosoma truncatellum*, and *Trichogramma* spp.

Natural Virus. A natural outbreak of nuclear polyhedrosis virus also sometimes provides control of the looper population.

Chemical (Registered Products)

Bacillus thuringiensis. 0 day PHI. *Bacillus thuringiensis* (Bt) is applied at label rates to a majority of the strawberry acreage (total is hard to determine because each Bt is reported as a separate pesticide). Applications are made when plants are dry, and good coverage at relatively low dilution rates is essential to product performance. Treatments are made when armyworms are still small. To be effective it must be applied no later than the second instar. Most Bt are acceptable for use on organically grown produce. The restricted-entry interval for Bt is 4 hours.

Diazinon. 5 days PHI. Diazinon is applied to strawberry fields at a rate of 0.8 lb ai/acre. Diazinon is not used unless loopers pose a serious threat to the crop. Diazinon is harmful to mite predators and outbreaks of twospotted spider mites may occur following its use. Diazinon was used to treat around 12% the state's strawberry acres in 2000. The restricted-entry interval for diazinon is 24 hours.

Chlorpyrifos. 21 day PHI. Chlorpyrifos (LORSBAN) is an broad-spectrum insecticide applied at an average rate of 1 lb ai/acre. It was applied to approximately 13% of strawberry acreage in 2000. Applications are typically made pre-bloom. Chlorpyrifos provides economic control but kills beneficial and nontarget organisms. The restricted-entry interval for chlorpyrifos is 24 hours.

Methomyl. 3 day PHI for fresh and 10 day PHI for processing strawberries. Methomyl (LANNATE) is a carbamate that can be used to control cabbage looper and several other pests in strawberries. Average applications rate are about 0.9 lb ai per acre, usually with a single application made per season. Methomyl was applied to about 31% of strawberry acreage in 2000. There is a 48 hour restricted-entry interval for methomyl.

Chemical (Unregistered Products)

The following active ingredient is are not currently registered for use on strawberries but is needed as soon as possible. Expedited registration is encouraged by the industry.

Spinosad. This new active ingredient is not currently registered for use on strawberries but may be in the future.

Methoxyfenozide. This new insect growth regulator (INTREPID) is not currently registered for use on strawberries but could be an important tool for the strawberry industry.

CORN EARWORM
A.k.a.: Tomato Fruitworm, Cotton Bollworm
Heliothis zea
Helicoverpa Zea

Damage. The south coastal zone is the only location where corn earworms can become a significant problem. Problems are most severe when the field is in close proximity to a corn or tomato field. Corn earworms damage strawberries by burrowing into fruit. Although there are several generations each season, only larvae of the first generation attack winter strawberries. Entrance holes made by early instar larvae are not visible, and the fruit must be cut to determine their presence. Contamination of the fruit prevents it from being marketed as whole fruit. Federal tolerance currently requires downgrading to juice stock if a single 7 mm or larger larva is found per 44 pounds of fruit (about 1,100 berries).

Description of Pest. Adult corn earworms are light grayish brown moths. Larvae typically feed within the fruit. Mature fruit containing large larvae appear seedy and develop a shrunken surface with one or more brown patches. The time needed to complete a generation is temperature dependent, but often takes about 1 month.

Monitoring. Growers monitor yearly for corn earworm in the south coast region using pheromone traps. Pheromone traps help monitor emergence and flight activity of the moths in late February/early March. When unparasitized eggs are found in the strawberry field, growers consider chemical treatments. Outbreaks of corn earworms often occur in years when warm air currents associated with El Niño conditions allow moths to migrate from the south. Monitoring is increased under these conditions.

CONTROLS

Cultural

Corn Grow in Close Proximity. Growers have planted a very early maturing sweet corn cultivar around strawberry fields to provide an alternate, and more attractive host plant for the corn earworm in an effort to reduce the impact of this pest on strawberries. The theory was that female moths strongly prefer corn to lay their eggs and will leave strawberries alone if corn or other preferred hosts are available to them. However, the use of a corn as an alternate host or a windbreak in close proximity with strawberries can also enhance corn earworm populations and infestations on strawberries, so this cultural control concept may not be viable for many growers.

Biological

General Predators. A number of predaceous insects and parasites will feed on corn earworm eggs. A tiny parasitic wasp, *Trichogramma pretiosum*, has been found developing in *Helicoverpa* eggs on strawberries, but the percent parasitization from natural populations appears to be low. *Trichogramma* can be purchased from commercial sources for augmentative release. The minute pirate bug is a predator that has been observed to feed on corn earworm eggs. While both of these biocontrol agents can provide some pest suppression, the very low tolerance for insect contamination in strawberries makes this control option less effective when populations are high.

Chemical

Methomyl. 3 day PHI for fresh strawberries and 10 day PHI for processing strawberries. Methomyl (LANNATE) is a carbamate insecticide. Typically, 0.9 lb ai/acre applied with a single application per year though multiple applications are allowed. Methomyl was applied on about 31% of the strawberry acreage in 2000. Use of methomyl often results in mite problems. There is a 48 hour restricted-entry interval for methomyl.

Bacillus thuringiensis. 0 day PHI. *Bacillus thuringiensis* (Bt) is most effective against newly hatched larvae and not very effective against large larvae and those that have already entered the fruit to feed. Treatments must be carefully timed to egg hatch. Because residual activity is short, repeat applications at 4- to 7-day intervals is often necessary during extended periods of peak egg hatch. Bt is applied at label rates to a majority of strawberry acres. Most Bt are acceptable for use on organically grown produce. The restricted-entry interval for Bt is 4 hours.

Chlorpyrifos. 21 day PHI. Chlorpyrifos (LORSBAN) is an broad spectrum organophosphate applied at an average of 1 lb ai per acre and was applied to approximately 13 % of strawberry acreage in 2000. Chlorpyrifos is an effective tool in the control of corn earworm. Provides economic control but kills beneficial and nontarget organisms. There is a 24 hour restricted-entry interval for chlorpyrifos.

EUROPEAN EARWIG
Forficula auricularia

Damage. Earwigs are a pest of the south coast region. Earwig feeding results in small deep holes in the fruit that can only be distinguished from slug damage by the absence of slime.

Description of Pest. Earwigs feed at night and can be found hidden around crowns of plants during the day. They are slender brown insects, about 0.5 to 0.75 inch long. They have a conspicuous pair of pincers attached to back end of the abdomen. The pest becomes most destructive as nymphs approach maturity from April to July.

Monitoring. When significant fruit splitting occurs, applications of bait are needed if earwigs are present

CONTROLS

Cultural

Sanitation. Field sanitation is important in the control of earwigs. Rubbish near strawberry fields should be destroyed or removed.

Biological

No significant biological controls are known.

Chemical

Carbaryl. 7 day PHI for bait. Carbaryl (SEVIN) bait is a carbamate bait that can be applied to strawberry beds around the base of the plants at a rate of 1.6 lb ai/acre. Carbaryl was applied to approximately 28% of treated strawberry acres in 2000 to control several insect pests. The 7-day PHI makes the material less useful in the past for use during harvest season. The restricted-entry interval is 12 hours.

HOPLIA BEETLE
WHITE GRUBS
Hoplia oregona

Damage. Hoplia larvae, or white grubs, typically feed on perennial grasses but may attack strawberries feeding on the roots of strawberry plants. Small rootlets may be devoured and the bark and cortex of larger roots destroyed. Injured plants wilt as the roots can no longer provide moisture

from leaves. Hoplia may be found throughout California but is most frequently found in the Central Valley. Damage is rarely seen in fumigated fields. Hoplia larvae has become a serious pest in nonfumigated fields in the Central Valley, where it has killed half the plants in heavily infested fields.
Description of Pest. Adults are brown beetles that are active for about two weeks after emerging in May, feeding on plants, mating and laying eggs on the soil. Adults are inconspicous because they fly poorly. Hoplia larvae are white grubs that feed on plant roots for up to two years before pupating. Soil fumigation has kept white grubs from becoming a problem.

Monitoring. Growers monitor the fields for evidence of beetles or damage from larvae. Injured plants often develop in a small circular area. Though some damage is acceptable, sever damage triggers control methods.

CONTROLS

Cultural

Crop Rotation. Annual plantings reduce the likelihood of high populations building in fields. Crop rotation with non-host cover or cash crops may also help reduce infestations.

Weed-Host Control. Control of host plants adjacent to fields helps to reduce the potential for infestation.

Biological

No known biological controls of hoplia larvae.

Chemical

Soil Fumigation - General. Soil fumigation with methyl bromide and chloropicrin for weed and disease control has greatly reduced the presence and effect of Hoplia beetle and white grubs. Currently, Hoplia beetles rarely require management due preplant fumigation. However, with the impending loss of methyl bromide as a soil fumigant, it may be anticipated that Hoplia beetle management throughout the growing regions will increase.

Methyl Bromide with Chloropicrin. This combination of fumigants, when used preplant to control weeds, nematodes and other pests, also controls garden symphylans. Methyl bromide is being phased out so this sole chemical pest management tool will not be available and alternate controls are not yet fully available. Infestations by grubs could become worse in future years as a result of this transition

GARDEN SYMPHYLAN

Scutigerella immaculata

Damage. Garden symphylans damage plants by feeding on roots, thus retarding plant growth. They are usually only a problem in fields that were not fumigated, or if the fumigation was ineffective.

Description of Pest. Garden symphylans are slender and white. They occur mainly in moist soils with good structure and a high organic matter content, and are often associated with debris from a previous crop that is not completely decomposed. Since these pests rarely leave the vicinity of their infestation, they return to damage the same area every season so infestations spread slowly.

CONTROLS

Cultural

Flooding. Continuous flooding for 3 weeks in the summer helps reduce infestations though this practice is not feasible.

Crop Rotation. Growers sometimes grow and disc in a cover crop of sorghum to reduce infestations in other crops.

Biological

There are no known biological controls that specifically target the garden symphylan.

Chemical

Soil fumigation, with methyl bromide and chloropicrin, for weed and disease control also controls garden symphylans. None of the registered insecticides will control this pest.

Methyl Bromide and Chloropicrin. This combination of fumigants, when used preplant to control weeds, nematodes and other pests, also controls garden symphylans. Methyl bromide is being phased out so this chemical pest management tool will not be available and alternate controls are not yet fully available. Infestations by symphylans could become worse in future years as a result of this transition.

GARDEN TORTRIX
Ptycholoma (Clepsis) peritana

Damage. Contamination of south coast fields just before the berries are sent to the processors during late June and July can be a serious problem. Garden tortrix larvae generally feed on dead and decaying leaves and fruit usually causing no significant damage. However, as the population increases and the plant canopies close in, more ripening berries settle down into the trash among the tortrix larvae. When this happens, larvae will often spin a nest in creases along the berry's surface and chew small, shallow holes in the berry, incidental to their scavenging. With the higher populations often attained by late spring or early summer, significant fruit losses can result from both larval contamination and secondary rots invading the feeding holes.

Description of Pest. The adult has the typical bell-shaped tortricid moth wings while at rest. Adults aren't usually seen until March or April. Larvae hatching from eggs laid in spring on older leaves move down into the trash where they feed on dead and decaying leaves. They construct shelters by tying bits of trash together. As a result of overlapping generations, all stages are generally present in spring and summer.

Monitoring. Late May, June, and early July are generally when treatments may be required. Chemical control is difficult to achieve due to the location of the larvae down in the litter beneath the protective canopy of strawberry leaves.

CONTROL

Cultural

Trash Removal. This is the most important control method since the populations build up on dead leaves. When populations can no longer be supported on dead material, they go onto live plants. In areas with a chronic tortrix problem, growers remove accumulated trash around the plants in spring with either blowers or suction devices to limit the potential for a large population buildup. In severe situations, extra help may be required to sort out contaminated or damaged berries during harvest.

Biological

There are no known biological controls that specifically target garden tortrix.

Chemical

***Bacillus thuringiensis*, subsp. kurstaki.** 0 day PHI. *Bacillus thuringiensis* (Bt) is applied at label rates to much of the strawberry acres (total is difficult to calculate because CDPR reports each Bt as a separate pesticide). Bt is acceptable for use on organically grown produce. The restricted reentry interval is 4 hours.

SALTMARSH CATERPILLAR
Estigmene acrea

Damage. Saltmarsh caterpillar is occasionally a pest in the Fall in southern growing regions when hot temperatures prevail. When saltmarsh caterpillars first hatch, they remain clustered and feed on the undersides of the leaves where the egg mass was laid. They skeletonize the foliage. As caterpillars grow, they eat holes in the leaves. This type of damage is generally of little or no concern, but the caterpillars can also make superficial bites in the fruit, causing significant economic loss.

Description of Pest. Adult moths are white with orange abdomens. Mature caterpillars are almost 2 inches long. Emerging moths lay their round, shiny eggs in several rows forming a neat cluster on the undersides of leaves. There are several generations each year.

CONTROLS

Cultural

Barriers. Caterpillars migrating from adjacent fields or uncultivated areas can be stopped by a physical barrier such as a plowed ditch, a ditch of water, or a slippery, vertical aluminum foil fence several inches tall.

Biological

Natural Predators. Young larvae have a high mortality rate, perhaps from a naturally occurring virus, which helps to limit populations. There are also a number of natural enemies, including parasitic wasps and flies that help to control this pest.

Chemical

Bacillus thuringiensis. 0 day PHI. *Bacillus thuringiensis* (Bt) sprays are best applied when the young caterpillars are still in the gregarious, skeletonizing phase. Bt is applied at label rates to much of the strawberry acres (total is difficult to calculate because CDPR reports each Bt as a separate pesticide). Good coverage at relatively low dilution rates is essential to product performance. Bt is acceptable for use on organically grown produce. The restricted-entry interval for Bt is 4 hours.

VINEGAR FLY

Drosophila melanogaster and other species

Damage. Vinegar flies (a.k.a., fruit fly) are primarily a problem in strawberries picked for processing. In general, the vinegar fly can be a problem from the Oxnard Plain south. Because this fruit is allowed to ripen in the field to allow easy removal of the calyx and core of the strawberry during picking, the harvest interval is increased and the fruit becomes more susceptible to infestation. Vinegar flies are attracted to very ripe or damaged fruit in the field where they lay their eggs. Eggs and larvae are primarily a contamination problem.

Description of Pest. Vinegar flies, also known as fruit or pomace flies, are small, yellowish flies. This pest has become more important in recent years with an increasing need for alternative control methods.

Monitoring. No monitoring or treatment guidelines exist for vinegar flies in strawberries, although yellow sticky cards are sometimes used to monitor adult fly populations. Adults and their offspring may be monitored with fermented fruit traps consisting of a container filled with overripe fruit covered with an inverted funnel.

CONTROLS

Cultural

Removal of Ripe Fruit. Growers limit breeding sites for fruit flies by making certain that ripe fruit are completely removed from the plants. When possible, harvest intervals are shortened as temperatures increase.

Sanitization. Good sanitation is practiced in and around the field with growers cleaning up external sources of flies such as cull piles of strawberries or other rotting fruit in nearby acreage, such as citrus groves, where old fruit may be on the ground. This practice is rarely performed due to labor costs and worker shortages.

Biological

There are no known biological controls that specifically target vinegar flies.

Chemical

Vinegar fly eggs and larvae in the berries cannot be killed using insecticides. Treatments are applied to kill adult flies.

Naled. 1 day PHI. Naled (DIBROM) is the most common treatment for vinegar flies. Naled (DIBROM) is an organophosphate that is applied at rates of about 1 lb ai per acre. It was applied to about 23% of the state's acreage in 2000. When used naled is typically applied once a year. Naled provides good late season aphid control but is not used when temperatures exceed 85°F due to plant phytotoxicity. Naled is typically limited to regions where the end of the season is cool. The restricted-entry interval for naled is 48 hours.

Malathion. 3 day PHI. Malathion provides effective control of vinegar flies This chemical works well in IPM programs. Effective control requires multiple applications, as residual is short-lived. Statewide, the number of repeat malathion applications per year is 4, but these applications often target Lygus bugs. Malathion was applied at a rate of 1 lbs ai per acre to about 65% of strawberry acreage in 2000. The restricted-entry interval for malathion is 12 hours.

Methomyl. 3 day PHI for fresh strawberries and 10 day PHI for processing strawberries. Methomyl (LANNATE) may be applied at a rate of about 0.9 lb ai/acre. Methomyl was applied to 31% of strawberry acreage. The restricted-entry interval for methomyl is 48 hours.

Diazinon. 5 day PHI. Diazinon is applied to strawberry fields at an average rate of about 0.8 lb ai per acre with an average of 1 application per year. Diazinon was used to treat about 12% of strawberry acres in 2000. The restricted-entry interval for diazinon is 24 hours.

Pyrethrin. 0 day PHI. Pyrethrin is applied at 0.03 lb ai per acre and was applied to 4% of treated strawberry acreage in 2000. Pyrethrins are less effective and more costly than other products and are not the first choice tool for control. Use of pyrethrins requires multiple treatments to obtain control. There is a 12 hour restricted-entry interval for pyrethrin.

Azinphos Methyl. 7 day PHI. Azinphos methyl (GUTHION) applications are rarely used against vinegar flies because the pre-harvest interval is relatively long and the reentry intervals are even longer (most greater than 30 days). Azinphos methyl use on strawberries will be cancelled within the next year by EPA.

NEMATODE PESTS

It is important to note that all discussion related to nematode control are based on pest management strategies utilizing certified pest/disease free nursery stock growing in soil treated with methyl bromide/chloropicrin.

FOLIAR NEMATODE
Aphelenchoides fragariae

NORTHERN ROOT KNOT NEMATODE
Meloidogyne hapla

Symptoms and Damage. The presence of either foliar or northern root knot nematodes may result in plant stress and reductions in yield. Under current practices of fumigating strawberry fields with methyl bromide and chloropicrin and using certified nursery stock, these nematodes are rarely found to cause significant damage in California production areas. However, with the impending loss of methyl bromide and the increasing use of organic methods damage will likely become more common. Control of these two pests by nursery stock producers is critical because an infestation will prevent the grower from receiving government certification, thereby reducing the value of the planting stock.

Plant symptoms can be indicative of a nematode problem but are not fully diagnostic because similar symptoms could result from other problems as well. The symptoms may either be widespread or may appear in small patches within a field. Aboveground symptoms of foliar nematode include stunted growth, reddened leaves, small curled or crinkled leaves (crimp), deformed buds and flowers, and a reduction in flowering and fruiting. A reduction in flowering and fruiting may more reliably distinguish a foliar nematode infestation from insect infestations, which produce leaf symptoms similar to those described above. There are no reported below-ground symptoms with foliar nematodes. Aboveground symptoms of root knot nematodes include wilting during hot days, stunting, chlorosis, and suppression of fruit yields. Root galls formed near the root tips and abundant branching at and above the galls are the primary below ground symptoms of this pest.

Description of Pest. Plant parasitic nematodes are microscopic, unsegmented roundworms. The two species most commonly associated with damage in California strawberries are the foliar nematode, *Aphelenchoides fragariae*, and the northern root knot nematode, *Meloidogyne hapla*. Strawberries are also hosts for the following nematodes: root lesion (*Pratylenchus penetrans*), stem (*Ditylenchus dipsaci*), dagger (*Xiphinema americanum*), needle (*Longidorus elongatus*), foliar (*Aphelenchoides ritzemabosi, Aphelenchoides besseyi*), and root knot (*Meloidogyne incognita* and *Meloidogyne javanica*). All of these nematodes are potential pathogens to strawberries in California and their identification in strawberry plantings or in land to be planted to strawberries cause concern.

Monitoring. To make management decisions, a grower must monitor the field by taking soil and plant samples, sending them to a diagnostic laboratory for identification. Sampling and extraction techniques are typically 30 to 50% effective in detecting species that might be present.

CONTROLS

Cultural

Limitations on Transfer of Pest. The selection of planting site, non-infested planting stock, cleaning of equipment to minimize nematode transfer, avoidance of nematode-infested irrigation water, hot water treatments of planting stock, and crop rotations are cultural techniques used by growers to control nematode infestations.

Solarization. There has been some experimentation where solar energy and has been used to help suppress nematode populations. It is not yet clear whether this technique can be a feasible alternative within an IPM program.

Biological

There are no known biological control agents that have been shown to control or suppress nematodes.

Chemical

Methyl Bromide. Methyl Bromide is applied as a preplant soil application to fields at a combined rate, with chloropicrin, of 300 to 400 lbs/acre. It is typically applied in combination to essentially all of the state's acreage to provide control of pathogenic fungi, weeds, and nematodes. When used properly, methyl bromide provides excellent preplant control of root-infesting plant parasitic nematodes. Methyl bromide is a restricted use material that may only be applied by permit from the county agricultural commissioner. Methyl bromide is being phased out with interim reductions and will not be available for use starting 2005.

Metam Sodium. Metam sodium is applied as a preplant soil fumigant to approximately 2% of strawberry fields primarily for weed control. Metam-sodium can control nematodes provided it gets to the target organism. These problems are due largely to nonuniformity of application as a result of land preparation and insufficient water for movement resulting in subsequent failure of the material to contact and kill the nematodes present. The restricted-entry interval for metam sodium is 48 hours.

Oxamyl. Oxamyl is only registered for use on root knot (except Javanese), sting, burrowing, and root lesion nematodes on nonbearing nursery stock that will not bear fruit within 12 months after application. For preplant soil incorporation, 6-8 lbs a.i./acre are applied. For foliar treatment, 0.5-1 lb a.i./acre are applied. Some cultivars have exhibited phytotoxic symptoms; therefore, oxamyl is typically used on a small scale to determine crop sensitivity prior to large scale field application. The restricted-entry interval is 48 hours.

Chloropicrin. Chloropicrin is typically applied in combination with methyl bromide for the control of pathogenic fungi, weeds, and nematodes. Efficacy data for chloropicrin alone is poor for nematode control on strawberries and is typically not used alone.

PRIMARY DISEASES

It is important to note that all discussion related to disease control are based on pest management strategies utilizing certified pest/disease free nursery stock growing in soil treated with methyl bromide/chloropicrin.

BOTRYTIS FRUIT ROT

Botrytis cinerea

Damage. Botrytis Fruit Rot or Gray Mold is the most common and most serious disease of strawberry fruit in California. This disease can affect all parts of the plant. Both fruit and nursery production are impacted. It is estimated that botrytis damage can reduce the value of California's harvest by 30 to 40% compared to production where chemical methods of pest management are not practiced (8). This loss can be as high as 50% to 60% under conditions of severe disease challenge and when infestation in the field reaches this level the economic loss is 100%. Botrytis fruit rot occurs in all growing areas and can cause losses of fruit both in the field and after harvest. Infected berries maintain their original shape and take on a velvety grey brown coat of mycelium and spores. Initially, rotted areas are soft and mushy, becoming leathery and dry in the absence of high humidity. Direct infection of the berries also occurs if berries are exposed to free water. These infections develop in the same manner as flower-infected berries, but differ in that multiple initial lesions may appear anywhere on the berry's surface. For nurseries, damage to petiole and leaf tissue can be significant.

Description of Disease. Botrytis fruit rot is widespread. It can infect flowers on strawberry plants when spores landing on them are exposed to free water and cool temperatures. Infections can either cause flowers to rot or Botrytis can become latent. Latent infections resume activity on the berry later in the season. Both green and red berries are susceptible, but ripening berries rot faster. During the growing season, the fungus is constantly present.

Monitoring. Inoculum density and environmental conditions conducive to disease development (i.e., rain and cool temperatures) determine when fungicide applications are needed. Because these conditions are usually seasonal, a protective application of a fungicide is used typically to prevent germination of spores when conditions are ideal for disease development. Spray schedules thereafter are set according to disease pressure and environmental conditions.

CONTROLS

Control of Botrytis fruit rot ranges from repetitive fungicide treatments with no cultural control to intensive cultural methods with limited or no fungicide applications. Environmental conditions in various microclimates play an important role in determining control strategies. It is crucial to avoid or delay the onset of fungicide resistance. It is common practice to rotate the use of fungicides between chemicals that represent different chemical classes.

Cultural

Removal of Infected Material. Nothing can be done to escape the presence of this fungus. The level of inoculum in a particular field can be reduced by removing dead leaves and infected fruit. Removal and destruction of dead or infected plant material reduces the amount of inoculum capable of producing new infections.

Canopy Size. The spacing between rows is an important consideration in mitigating the severity of Botrytis fruit rot. Wider spacing allows for greater "breathing" room, conditions that do not favor botrytis infestation. In addition, the management of plant (canopy) size opens up the space between plants, allowing "breathing" room and air circulation.

Barriers/Mulches. Use of plastic mulches prevents berry-soil contact, thus reducing disease. For organic growers, it is important to select growing areas that have environmental conditions that are not conducive to disease development. Mulches that provide optimum air circulation may also help in control the disease.

Fertilizers. Excess fertilizer use, particularly too much nitrate fertilization, may enhance botrytis fruit rot development and result in adverse production and quality impacts. These impacts may be due to the effects on fruit integrity and strength.

Biological

No biological control agents are currently available to the industry that target botrytis fruit rot. *Trichoderma harzian* is being developed as a possible biological control agent but has not been commercialized yet on strawberries in California.

Chemical

It is crucial to avoid or delay the onset of fungicide resistance. As a result, fungicide applications are usually rotated through several active ingredients during a season, with fungicides of different chemical classes being applied in sequence. Use of repeated applications of the same or related fungicide is avoided. Due to the differences in price of the available fungicides, this approach can be financially challenging. Tank mixing of fungicides is also common, lowering the application rate required of any single fungicide.

Captan. 0 day PHI. Captan is a N-trihalomethylthio fungicide that provides good control of Botrytis in the coastal areas and is applied at 2 lb ai/acre to nearly all of strawberry acreage. It is applied anywhere from 1 to 12 times per season, with 3 applications per season being the average statewide (multiple applications per field are usually made at reduced rates in tank mixes with other fungicides). Under severe disease pressure, captan is used every 7-14 days. It is not applied in combination with or immediately following application of spray oils. The restricted-entry interval for captan is 24 hours.

Thiram. 3 day PHI. Thiram is a dithiocarbamate applied at 2 lb ai/acre at an average number of 2 applications per season. Thiram was applied to 70% of strawberry acreage in 2000. It is not applied in combination with or immediately following application of spray oils. The restricted-entry interval is 24 hours for thiram.

Benomyl. 1 day PHI. The manufacturer removed benomyl from the market in 2001 and it will no longer be available once existing stocks are used up, removing it as a resistance management tool. Benomyl (BENLATE) is a benzimidazole fungicide applied at an average rate of 0.5 lb ai/acre once a year to about 46% of the strawberry acreage in 2000. The label for benomyl requires its use in combination with other fungicides (e.g. captan, thiram). Resistance to benomyl is at very high levels and has been identified in all strawberry growing regions. To reduce the likelihood of resistance development, applications are typically alternated with products of different chemistry (e.g., captan, fenhexamid, or thiram). The restricted-entry interval for benomyl is 24 hours.

Thiophanate-Methyl. 1 day PHI. Thiophanate-methyl (TOPSIN) is applied at an average rate of 0.7 lb ai/acre once a year and is the same mode of action as benomyl with similar resistance problems. It has historically only been used on minimal strawberry acreage but use is anticipate to increase with the loss of benomyl. It is usually used in combination with a fungicide of a different chemistry class (such as captan or thiram) to reduce resistance problems. The restricted-entry interval for thiophanate-methyl is 12 hours.

Fenhexamid. 0 day PHI. Fenhexamid (ELEVATE) is a hydroxyanilid protectant fungicide, a new mode of action for resistance control. It has been classified as a reduced-risk pesticide by the USEPA. It was applied at a rate of 0.75 lb a.i./acre with an average of 2 applications per season (4 are allowed). To avoid resistance development rotation with applications of other mode of action fungicides is highly recommended. In 2000 it was used on 63% of the strawberry acreage. The restricted-entry interval period is 4 hours.

Cyprodinil With Fludioxonil. 0 day PHI. The combination of cyprodinil and fludioxonil (SWITCH) was registered late in 2001 in California. Combined new chemistries, very effective against Botrytis, but limited to use in fields rotated to strawberries or onions 12 months after use. Applications of 11-14 ounces product are made 2 to 4 times a season in rotation with other fungicides. The restricted-entry interval is 12 hours.

Chitosan. Chitosan (ELEXA) is a new biological pesticide effective on powdery mildew and provides suppression of botrytis. The PHI is 0 days and the restricted-entry interval is 4 hours.

Iprodione. Pre-bloom only. Iprodione (ROVRAL) is a dicarboximide fungicide applied either as a dip or foliar treatment at an average rate of 1 lb ai per acre. With the transition from existing stock to pre-bloom use, the percentage of strawberry acreage in future is unknown. Iprodione is limited to 1 pre-bloom application, thus eliminating iprodione as a fungicide resistance management tool. The restricted-entry interval for iprodione is 24 hours

The following active ingredients are not currently registered but are needed as tools as soon as possible. An expedited registration is encouraged by the industry.

Azoxystrobin. (QUADRIS) has activity against Botrytis and registration primarily for use on powdery mildew is anticipated in late 2001.

Triflumizone. (PROCURE) also has activity, but registration is uncertain for use on strawberries.

VERTICILLIUM WILT
Verticillium dahliae

Damage. Verticillium wilt is becoming an increasingly important disease in California strawberries. It is slow growing but, once established, it is extremely difficult to eradicate. Spread of the disease from contaminated planting stock is an increasing concern, making control of this disease at the nursery stage crucial. The pathogen is a soil-borne fungus and the loss of the methyl bromide/chloropicrin combination fumigant is anticipated to have a significant adverse effect by increasing the prevalence of Verticillium wilt. Verticillium wilt causes outer leaves to exhibit marginal and interveinal browning, followed by eventual collapse. Inner leaves remain green but are stunted and exhibit brownish black streaks or blotches. This last symptom distinguishes this disease from crown rot. Outbreaks of the disease typically result in observable "streaks" or "stripes" within the field.

Description of Disease. The fungus is not host specific and infects many weed species and crops worldwide. It is especially destructive in semi-arid areas where soils are irrigated.

Inoculum densities may be high following planting of susceptible crops. Disease severity is greater when excessive levels of nitrogen are used.

Monitoring. The most common indication of Verticillium wilt is the observation of brown or dead outer leaves with green inner leaves.

CONTROL

Cultural

Fertilizer Limitation. High nitrogen fertilizers are avoided since the disease severity is greater when levels of soil nitrogen are excessive.

Crop Rotation. Growers with infested fields can rotate the fields to crops that are less susceptible to verticillium wilt. However, Verticillium infects a wide variety of crops and relatively few rotational crop choices are viable. Also, Verticillium wilt (microsclerotia) may remain viable in soil for up to 20 years suggesting that a rotation cycle of 20 years or more is necessary.

Irrigation Control. Use of drip irrigation and other irrigation practices that limit spread of this soil-borne disease can be helpful.

Fertilizer Limitation. High nitrogen fertilizers are avoided since the disease severity is greater when high levels of soil nitrogen are present.

Field Selection. Selection of fields that are free of the disease is an important factor. In particular, organic growers try to select fields isolated from conventional growing areas, when possible.

Resistant Cultivars. Growers can use less susceptible cultivars when practical, though resistance to Verticillium wilt is rarely an important criteria selection of current commercial varieties. However, all current California varieties are susceptible to Verticillium wilt in comparison to other crop hosts.

Chemical

Chloropicrin. Though currently applied in combination with methyl bromide, chloropicrin is the more effective of the two fumigants against Verticillium wilt. When used alone chloropicrin at rates of less than 200 lb ai per acre are not sufficiently effective. If Verticillium wilt is an important concern in the treated field, the proportion of chloropicrin to methyl bromide is increased. Chloropicrin is more effective for Verticillium wilt when used in combination with methyl bromide than when used alone. Chloropicrin is currently applied to almost all the strawberry acreage in California in combination with methyl bromide. San Diego County does not permit the use of chloropicrin alone. There are numerous restrictions on the application of this restricted-use pesticide.

Methyl Bromide/Chloropicrin. Methyl Bromide with Chloropicrin is applied as a preplant soil application to fields at a combined rate of 300 to 400 lbs/acre. It is currently applied to essentially all of the commercial acreage, both production and nursery, in California. Since chloropicrin is the more effective of these two chemicals against Verticillium wilt, the relative proportion of chloropicrin is increased in fields where the control of this disease is important. There are numerous restrictions on the application of these restricted-use pesticides.

Metam Sodium. Metam sodium is applied as a preplant soil drench to less than 1% of treated fields. Metam-sodium can be a marginally effective preplant material provided it gets to the target organism. Metam sodium delays growth of Verticillium but does not get down deep enough in the soil to effectively control the disease. There are numerous restrictions on the application of this restricted-use pesticide.

RHIZOPUS FRUIT ROT
Rhizopus spp.

Damage. The fungus lives on and helps break down decaying organic matter. It invades strawberries through wounds and secretes enzymes that degrade and kill the tissue. Under conditions of high relative humidity, the berry rapidly becomes covered with a coat of white mycelium and spores. After high temperatures, the disease can become quite destructive. Outbreaks of the disease have caused 20 to 35% loss in production in the Oxnard plain.

Description of Disease. Initial infections appear as discolored, water-soaked spots on fruit. These lesions enlarge rapidly, releasing enzymes that leave the berry limp, brown, and leaky. The sporangiophores develop black sporangia, each containing thousands of spores. When disrupted, these sporulating berries release a cloud containing millions of sporangiospores.

Monitoring. Observations of twig die-back indicates presence of the disease.

CONTROLS

Cultural

Sanitation. Field sanitation also is extremely important: growers do not leave discarded plant refuse or berries in the furrows, and remove all ripe fruit from the field.

Post-Harvest Cooling. *Rhizopus* stops growing at temperatures around 46 to 50°F (8 to 10°C), so rapid postharvest cooling of fruit is essential for disease control.

Varietal Effects. Growers select cultivars with thick cuticles that are less susceptible to Rhizopus Fruit Rot in diseased areas because they are better able to resist infection.

Biological

There are no biological control techniques specific to Rhizopus Fruit Rot at this time.

Chemical

There are no chemical treatments that are highly effective against Rhizopus Fruit Rot but the following chemicals can be used.

Thiram. 3 day PHI. Thiram is a dithiocarbamate applied at an average rate of 2 lb ai/acre and was applied to 70% of strawberry acreage in 2000. Again, the primary target of these applications is the control of Botrytis, not Rhizopus. Applications against Rhizopus are made only during outbreaks of the disease. The average number of annual applications of thiram on a field is 2. It is not applied in combination with or immediately following application of spray oils. The restricted-entry interval for thiram is 24 hours.

Captan. 0 day PHI. Captan is a N-trihalomethylthio fungicide that provides good control of Rhizopus and is applied at 2 lb ai/acre to 100% of strawberry acreage. It is applied anywhere from 1 to 12 times per season, with 3 applications per season being the average statewide (multiple applications per field are usually made at reduced rates in tank mixes with other fungicides). Under severe disease pressure, captan is used every 7-14 days. It is not applied in combination with or immediately following application of spray oils. The restricted-entry interval is 24 hours.

POWDERY MILDEW
Sphaerotheca macularis

Damage. Powdery mildew is mostly limited to the coastal growing regions and northern nurseries, and causes very little damage in inland growing regions. Infestations during the 1990s have been the worst in the central coastal region. Some of the differences in vulnerability are due to the different varieties that are grown in these different regions. Infected flowers produce deformed fruit or no fruit at all. Severely infected flowers may be completely covered by mycelium and killed. Infected immature fruits become hardened and desiccated, often resulting in the observation of fruit "bronzing". Infected leaves initially produce small, white powdery colonies on the undersides of leaves.

Description of Disease. Colonies of powdery mildew multiply to cover the entire lower leaf surface, causing the edges of the leaves to roll up. Purple-reddish blotches appear on the upper and lower surface of leaves. Infected mature fruits become seedy in appearance and support spore-producing colonies that look powdery and white. The disease overwinters as mycelium on leaves in California, so it is most likely introduced into the field through planting material or spores from neighboring fields. Ideal conditions for infection are dry leaf surfaces, high relative humidity, and cool to warm temperatures.

Monitoring. Early signs of the disease are monitored since preventative control is most effective. Applications are often tied to models based on meteorological observations.

CONTROL

Cultural

Resistant Cultivars. Growers use resistant cultivars where practical. Use of these varieties is typically region dependent with few of the varieties used in the central coast region being resistant to powdery mildew. Statewide, the most common varieties used in production are all relatively susceptible to powdery mildew.

Overhead Irrigation. Overhead irrigation is avoided as it enhances the onset and severity of the disease.

Biological

Ampelomyces quisqualis. 0 day PHI. *Ampelomyces quisqualis* (AQ10) is a biofungicide which is a selective fungal hyperparasite. Use rates are from 0.5 - 1.0 oz/acre. This product works well early in the season but is less effective in inland growing regions. It is also incompatible with other fungicides so its use is usually limited to the early season in coastal growing regions. This biological control is registered under FIFRA as a pesticide, and was applied to 1.6% of the strawberry acreage in 2000. The restricted-entry interval is 4 hours.

Chemical

Controlling the disease on leaves with fungicides does increase yields, though losses are almost entirely due to infection of flowers and fruit. Flower and fruit infections generally are the result of severe leaf infections. Protective fungicides are used to protect flowers and fruit. Fungicides are applied about 1 month after planting and again 3 to 4 weeks later. Additional treatments are made when plants begin to bloom.

Myclobutanil. 3 day PHI. Myclobutanil (RALLY) is an azole fungicide applied at a rate of 1 – 2 oz. ai/acre and offers good long-term control. It was applied to 81% of strawberry acres in 2000. The average number of applications per year is 2 though up to 6 applications per year are allowed. The restricted-entry interval for myclobutanil is 24 hours.

Micronized Sulfur. 0 day PHI. Micronized sulfur is applied at rates averaging 3.2 lb ai/acre and requires multiple treatments for control (the average number of annual applications is 3). Sulfur should be applied in cooler climates as applications during high temperatures can cause phytotoxicity to plants burning the foliage. It should also not be applied within 2 weeks of an oil application. Sulfur was applied to 100% of strawberry acreage in 2000. Application rates are significantly higher (typically 10-fold higher) for organic growers, where alternate products are not available or effective, particularly late season. The restricted-entry interval is 24 hours.

Benomyl. 1 day PHI. The manufacturer removed benomyl from the market in 2001 and it will no longer be available once existing stocks are used up, removing it as a resistance management tool. Benomyl (BENLATE) is a benzimidazole fungicide applied at an average rate of 0.5 lb ai/acre once a year to about 46% of the strawberry acreage in 2000. The label for benomyl requires its use in combination with other fungicides (e.g. captan, thiram). To reduce the likelihood of resistance development, applications are typically alternated with products of different chemistry (e.g., captan, fenhexamid, or thiram). The restricted-entry interval for benomyl is 24 hours.

Thiophanate-Methyl. 1 day PHI. Thiophanate-methyl (TOPSIN) is applied at an average rate of 0.7 lb ai/acre once a year and is the same mode of action as benomyl with similar resistance problems. It has historically only been used on minimal strawberry acreage but use is anticipate to increase with the loss of benomyl. It is usually used in combination with a fungicide of a different chemistry class (such as captan or thiram) to reduce resistance problems. The restricted-entry interval for thiophanate-methyl is 12 hours.

Cyprodinil With Fludioxonil. 0 day PHI. The combination of cyprodinil and fludioxonil (SWITCH) was registered late in 2001 in California. Combined new chemistries, with activity against powdery mildew, but limited to use in fields rotated to strawberries or onions 12 months after use. Applications of 11-14 ounces product are made 2 to 4 times a season in rotation with other fungicides. The restricted-entry interval is 12 hours.

Insecticidal Soap. 0 day PHI. Insecticidal soap is applied at rates of 5.5 lb ai/acre. It is not used on new transplants, un-rooted cuttings, or water-stressed plants and should not be applied when leaf temperature exceeds 90°F. These soaps can be phytotoxic at various stages of growth. The restricted-entry interval is 4 hours for insecticidal soap.

Potassium Bicarbonate. 0 day PHI. Potassium bicarbonate (KALIGREEN) is a new product available to the industry. Though less effective than traditional controls of powdery mildew, this product works well in rotation with these products and is a good reduced-risk addition to an IPM program. It should be applied in cooler climates as applications during high temperatures may cause bronzing of fruit. The product is applied at a rate of 2 – 2.5 lb ai per acre. Use has increased on strawberries in California and in 2000 was applied to 19% of the acreage. The restricted-entry interval for potassium bicarbonate is 4 hours.

Narrow Range Oil. Narrow range oils (such as STYLET OIL) may be alternated prebloom with other fungicides such as sterol inhibitors. Good coverage is essential for the product to be effective against powdery mildew.

Chitosan. Chitosan (ELEXA) is a new biological pesticide which can suppress powdery mildew in combination or rotation with other fungicides. Multiple applications are required. The PHI is 0 days and the restricted-entry interval is 4 hours.

The following active ingredients are not currently registered but are needed as tools as soon as possible. An expedited registration is encouraged by the industry.

Azoxystrobin (QUADRIS) has activity against powdery mildew and should be registered by the end of 2001 in California.

Trifloxystrobin (FLINT) has good activity against powdery mildew at 3 oz. a.i./acre, but is not registered on strawberries.

Quinoxyfen (QUINTEC) is also a potential replacement product on powdery mildew.

Triflumizole (PROCURE) is also a potential replacement product on powdery mildew.

Methyl (E)-methoxyimino[a-(o-tolyloxy)-o-tolyl] acetate (SOVRAN) is a strobulurin derivative with good activity against powdery mildew, but generally has a 14-30 day PHI on other crops. It is not registered on strawberries.

PHYTOPHTHORA CROWN ROT & ROOT ROT

Phytophthora cactorum
Phytophthora citricola
Phytophthora parasitica

Phytophthora megasperma

Damage. *Phytophthora* is a genus of soil-borne fungi. Stunting is common. Initially, the youngest leaves on the strawberry plant begin to wilt and also may turn bluish green in color. Plant collapse also occurs rapidly or slowly, depending on the *Phytophthora* species involved. When infected plants are cut open, a brown discoloration can be seen throughout the crown tissue. *Phytophthora* species also attack root tissue, causing a brown to black root rot.

Description of Infection. Motile spores (zoospores) are released into the soil and swim to plant tissue when the soil becomes saturated with water for prolonged time periods. When the soil drains and dries, zoospores either encyst or die. Mycelium in infected tissues form resistant structures that overwinter and survive harsh conditions.

CONTROL

Cultural

Low Moisture. Cultural control of the fungus includes locating strawberry fields on well drained soil, using raised beds to provide optimum drainage, and planting less susceptible cultivars. Use of drip irrigation and managing irrigation schedules to minimize soil saturation near plant crowns are key methods reducing losses from this pathogen. Planting in low lying areas that regularly receive excess water and are poorly drained is avoided.

Resistance/Prevention. In so far as possible, growers also use clean plant stock when available and cultivars suitable for local conditions that have disease tolerance.

Varieties. Though some varieties are less susceptible to Phytophthora, this is rarely an important basis for varietal selection by the growers. Furthermore, resistance in main varieties is incomplete to phytophthora.

Chemical

Methyl Bromide/Chloropicrin. Fumigating the soil with methyl bromide/chloropicrin is a key component of crown rot control, although the use of fungicide soil drenches or sprays is also of use. Methyl Bromide with chloropicrin is applied as a preplant soil application to fields at a combined rate of 300 to 400 lbs/acre to control Phytophthora crown rot. It is typically applied to essentially all of the fruit production acreage and to all nursery acreage in California. Methyl bromide applications are highly controlled and restricted and the active ingredient will no longer be available in 2005. There are numerous restrictions on the application of this restricted-use pesticide.

Mefenoxan. 1 Day PHI. Mefenoxam (RIDOMIL GOLD) is a purer form of the active isomer of metalaxyl (RIDOMIL) and has replaced use of metalaxyl. Mefenoxam is applied at 0.5 lb a.i./acre as a preplant or drip applied material an average of one time per season. In 2000, 12% of the strawberry acreage was treated. The restricted-entry interval is for mefenoxam is 48 hours.

Fosetyl-Aluminum. 0.5 day PHI. Fosetyl-al (ALIETTE) is used as a preplant dip (2 lbs/100 gal) or applied at 2-4 lbs a.i./acre to affected areas to slow the progress of the disease. Fosetyl-al was applied to about 16% of strawberry acreage in 2000. The restricted-entry interval is 12 hours.

COMMON LEAF SPOT
Ramularia tulasneii

Damage. Common leaf spot is the most important of the strawberry leaf spot diseases in California. The disease is not as important as it has been in previous years, particularly in south coast regions. However, the disease can decimate the productivity of fields if unchecked. The pathogen is introduced into fruit production fields as small, black sclerotia on infected nursery material. Germination of sclerotia is initiated by fall and winter rains or sprinkler irrigation. Spores are dispersed by wind-driven rain. Common leaf spot can be a problem in all nursery and fruit production areas, but is usually less prevalent in the drier interior valleys and southern growing regions.

Description of Infection. Small, deep purple spots initially appear on the upper surface of leaves, with the center portion of the lesion turning brown then grey to white depending on the age of the leaf and environmental conditions. Numerous spots may coalesce to kill the leaf. On petioles, stolons, calyxes, and fruit trusses, elongated sunken lesions may form and interfere with water transport in the plant, weaken the structure, or allow invasion by secondary organisms.

CONTROLS

Cultural

Drip Irrigation. Overhead irrigation is avoided. The use of drip irrigation can limit the onset of the disease.

Leaf Removal. Though not always practical, removal of infected leaves can limit spread of the disease.

Clean Stock. Attempts are made to insure that planting stock is clean, limiting introduction of the disease into a new field.

Protective fungicides are effective if used at the appropriate time. Applications are made in anticipation of warm, damp weather.

Methyl Bromide/Chloropicrin. Methyl Bromide with Chloropicrin is applied as a preplant soil application to fields at a rate of 300 to 400 lbs/acre to kill overwintering sclerotia. It is typically applied to essentially all fruit production acreage and all nursery acreage in the state. Methyl bromide/chloropicrin is effective against sclerotia in the soil. These applications are highly restricted and methyl bromide is being phased out by 2005. There are numerous restrictions on the application of this restricted-use pesticide.

Chlorothalonil. NURSERY ONLY. Chlorothalonil (BRAVO) is an aromatic hydrocarbon derivative applied at rates of about 1 lb ai/acre to nonbearing stock in nurseries only. It was applied to about 20% of strawberry nursery acreage in 2000. This material is available as a special local needs registration and may only be applied by permit from a county agricultural commissioner. Chlorothalonil should not be used with or closely following spray oils. The restricted-entry interval is 48 hours.

Captan. 0 day PHI. Captan is a N-trihalomethylthio fungicide and is applied at 2 lb ai/acre to 100% of strawberry acreage. It is applied anywhere from 1 to 12 times per season, with 3 applications per season being the average statewide (multiple applications per field are usually made at reduced rates in tank mixes with other fungicides). Under severe disease pressure, captan is used every 7-14 days. It is not applied in combination with or immediately following application of spray oils. The restricted-entry interval is 24 hours.

Benomyl. 1 day PHI. The manufacturer removed benomyl from the market in 2001 and it will no longer be available once existing stocks are used up, removing it as a resistance management tool. Benomyl (BENLATE) is a benzimidazole fungicide applied at an average rate of 0.5 lb ai/acre once a year to about 46% of the strawberry acreage in 2000. The label for benomyl requires its use in combination with other fungicides (e.g. captan, thiram). Resistance to benomyl is at very high levels and has been identified in all strawberry growing regions. To reduce the likelihood of resistance development, applications are typically alternated with products of different chemistry (e.g., captan, fenhexamid, or thiram). The restricted-entry interval for benomyl is 24 hours.

Thiophanate-Methyl. 1 day PHI. Thiophanate-methyl (TOPSIN) is applied at an average rate of 0.7 lb ai/acre once a year and is the same mode of action as benomyl with similar resistance problems. It has historically only been used on minimal strawberry acreage but use is anticipate to increase with the loss of benomyl. It is usually used in combination with a fungicide of a different chemistry class (such as captan or thiram) to reduce resistance problems. The restricted-entry interval for thiophanate-methyl is 12 hours.

Copper Hydroxide. 1 day PHI. Copper hydroxide provides some control of common leaf spot at an average rate of 1 lb a.i./acre and average of twice a season. It was applied to 5% of strawberry acreage in 2000. The restricted reentry interval is 24 hours.

Myclobutanil. 3 day PHI. Myclobutanil (RALLY) is an azole fungicide applied at a rate of 1 –2 oz. ai/acre. It wais applied to approximately 81% of strawberry acres in 2000 though primarily targeted towards powdery mildew. The average number of applications per year is 2 though up to 6 applications per year are allowed. Though effective against common leaf spot, it must be applied in conjunction with its targeted use against powdery mildew. The restricted entry interval for myclobutanil is 24 hours.

Potassium Bicarbonate. 0 day PHI. Potassium bicarbonate (KALIGREEN) is a new product available to the industry. Though less effective than traditional chemical treatments against common leaf spot, this product works well in rotation with these products and is a good reduced-risk addition to an IPM program. The product is applied at a rate of 2 – 2.5 lb ai per acre. It should be applied in cooler climates as applications during higher temperatures may cause bronzing of fruit. In 2000, it was applied to 19% of the strawberry acreage. The restricted reentry period is 4 hours.

ANTHRACNOSE
Colletotrichum acutatum

Damage. Anthracnose is a sporadic disease that is most common in wet, El Nino years , especially in Southern California. Flowers, ripe and unripe fruit can be affected. Warm or cool, wet conditions favor the development of fruit and stem rot. Anthracnose can also cause root rot and crown rot. The worst problems from this disease come from nursery stock.

Description of Disease. On fruit, light tan to light brown water-soaked lesions develop and turn into sunken black lesions. Dark elongated fusiform lesions appear on petioles and runners, and often girdle the stem. Fungus overwinters in plant debris or alternate weed hosts.

CONTROL

Cultural

Planting Stock. Anthracnose is most common on varieties that fruit in the nursery. Contamination may occur in fruit production fields as a result of nursery infections or contamination of planting material. Growers use certified "clean" pathogen-free planting stock in fruit production fields and use drip irrigation to prevent the spread of disease, avoiding overhead sprinkler irrigation.

Removal of Soil. Water (hot water, if possible) can be used to remove soil from planting stock prior to transfer and to reduce potential for transfer of disease.

Biological

There are no specific biological control methods for anthracnose.

Chemical

Methyl Bromide/Chloropicrin. Methyl Bromide with Chloropicrin is applied as a pre-plant soil fumigation to fields at a combined rate of 300 to 400 lbs/acre. It is applied to essentially all of California's production and nursery acreage. Methyl bromide use is highly restricted and will be phased out by 2005, with a 70% reduction by 2003. There are numerous restrictions on the application of this restricted-use pesticide.

Myclobutanil. 3 day PHI. . Myclobutanil (RALLY) is an azole fungicide applied at a rate of 1 –2 oz. ai/acre. It wais applied to approximately 81% of strawberry acres in 2000 though primarily targeted towards powdery mildew. The average number of applications per year is 2 though up to 6 applications per year are allowed. Myclobutanil can be effective against anthracnose but must be used in conjunction with treatments targeting powdery mildew. The restricted entry interval for myclobutanil is 24 hours.

Benomyl. 1 day PHI. The manufacturer removed benomyl from the market in 2001 and it will no longer be available once existing stocks are used up, removing it as a resistance management tool. Benomyl (BENLATE) is a benzimidazole fungicide applied at an average rate of 0.5 lb ai/acre once a year to about 46% of the strawberry acreage in 2000. The label for benomyl requires its use in combination with other fungicides (e.g. captan, thiram). Resistance to benomyl is at very high levels and has been identified in all strawberry growing regions. To reduce the likelihood of resistance development, applications are typically alternated with products of different chemistry (e.g., captan, fenhexamid, or thiram). The restricted-entry interval for benomyl is 24 hours.

Thiophanate-Methyl. 1 day PHI. Thiophanate-methyl (TOPSIN) is applied at an average rate of 0.7 lb ai/acre once a year and is the same mode of action as benomyl with similar resistance problems. It has historically only been used on minimal strawberry acreage but use is anticipate to increase with the loss of benomyl. It is usually used in combination with a fungicide of a different chemistry class (such as captan or thiram) to reduce resistance problems. The restricted-entry interval for thiophanate-methyl is 12 hours.

Captan. 0 day PHI. Captan is a N-trihalomethylthio fungicide applied at an average rate of 2 lb ai per acre. Captan is applied to 100% of the strawberry acreage several times to treat several fungal diseases. It is not applied in combination with or immediately following application of spray oils. The restricted entry interval is 24 hours for captan.

Cyprodinil With Fludioxonil. 0 day PHI. The combination of cyprodinil and fludioxonil (SWITCH) was registered late in 2001 in California. Combined new chemistries, with activity against anthracnose, but limited to use in fields rotated to strawberries or onions 12 months after use. Applications of 11-14 ounces product are made 2 to 4 times a season in rotation with other fungicides. The restricted-entry interval is 12 hours.

The following active ingredients are not currently registered for strawberries but are needed tools as soon as possible. An expedited registration is encouraged by the industry.

Azoxystrobin. Azoxystrobin (QUADRIS) is a new active ingredient that is needed for strawberries in California for disease control and to manage fungicide resistance. Registration is anticipated in late 2001.

SECONDARY DISEASES

It is important to note that all discussion related to pest control are based on pest management strategies utilizing certified pest/disease free nursery stock growing in soil treated with methyl bromide/chloropicrin.

LEATHER ROT
Phytophthora cactorum

Damage. Leather rot of strawberry fruit is not common on most annual plantings of strawberries in California. Plantings held for 2 or 3 years, however, can be infected by the leather rot pathogen. Infected fruit is bitter and has tough areas where infections appear.

Description of Infection. All stages of fruit are susceptible to leather rot. The fruit appears dull and lifeless, ranging in color from light purple to ripe red. The external infected area becomes tough, while the internal tissue is somewhat softer with vascular tissue turning dark brown. The fruit tastes bitter.

CONTROLS

There are very few options that are effective in control of leather rot. Though this disease is currently of little concern, the loss of methyl bromide may have a significant impact on the onset of this disease.

Cultural

Sanitation. Diseased fruit is removed from the field and plastic mulches are used to control the disease.

Drip Irrigation. Growers use drip irrigation, and avoid overhead irrigation.

Crop Rotation. Disease establishment can be limited by replanting annually or by rotating the fields through other crops.

Biological

There are no biological control methods that target leather rot.

Chemical

This disease is largely controlled through the widespread use of methyl bromide. The removal of this chemical from the marketplace is likely to cause an increase in the occurrence and severity of leather rot.

Methyl Bromide/Chloropicrin. Methyl Bromide with Chloropicrin is applied as a pre-plant soil fumigation to fields at a combined rate of 300 to 400 lbs/acre. It is applied to essentially all of California's production and nursery acreage. Methyl bromide use is highly restricted and will be phased out by 2005, with a 70% reduction by 2003. There are numerous restrictions on the application of this restricted-use pesticide.

The following products are potentially available for the control of leather rot but are not very effective and are rarely, if ever, used for this purpose.

Fosetyl-Aluminum. 0.5 day PHI. Fosetyl-al (ALIETTE) is applied at 2-4 lbs a.i./acre to affected areas to slow the progress of the disease. Fosetyl-al was applied to about 16% of strawberry acreage in 2000. The restricted-entry interval is 12 hours.

Captan. 0 day PHI. Captan is a N-trihalomethylthio fungicide applied at an average rate of 2 lb ai per acre. Captan is applied to 100% of the strawberry acreage several times to treat several fungal diseases. It is not applied in combination with or immediately following application of spray oils. The restricted entry interval is 24 hours.

Thiram. 3 day PHI. Thiram is a dithiocarbamate applied at an average rate of 2 lb ai/acre and was applied to 70% of strawberry acreage in 2000. The primary target of these applications is the control of Botrytis. The average number of annual applications of thiram on a field is 2. It is not applied in combination with or immediately following pplication of spray oils. The restricted-entry interval for thiram is 24 hours.

Mefenoxan. 1 Day PHI. Mefenoxam (RIDOMIL GOLD) is a purer form of the active isomer of metalaxyl (RIDOMIL) and has replaced use of metalaxyl. Mefenoxam is applied at 0.5 lb a.i./acre an average of one time per season. In 2000, 12% of the strawberry acreage was treated. The restricted-entry interval is for mefenoxam is 48 hours.

MUCOR FRUIT ROT
Mucor spp.

Damage. Mucor Fruit Rot is not a commonly seen disease in California strawberries though outbreaks do occur, often in conjunction with outbreaks of Rhizopus Fruit Rot. The disease invades the fruit through the slightest wound. Under conditions of high humidity, the berry becomes covered with a coat of tough, wiry mycelium and black spore-bearing structures. High temperatures trigger onset of the disease.

Description of Infection. Like the fungus that causes Rhizopus fruit rot, Mucor fruit rot invades the fruit through wounds. The fungus secretes an enzyme that rapidly results in a leaky fruit rot. The fungus produces millions of airborne spores that are favored by warm, moist conditions. Because the fungus lives on dead and decaying organic matter, field sanitation is important.

CONTROL

Cultural

Post-Harvest Cooling. Immediate post-harvest cooling of the berries can reduce the severity and impact of the disease though this practice does not work on all varieties. Unlike *Rhizopus*, some *Mucor* species such as *M. mucedo* and *M. piriformis* are not inhibited by cold temperatures.

Sanitation. Fields are kept clean of all plant debris. Growers remove all ripe fruit from the fields. After rains, all ripe and near ripe fruit is removed from fields and destroyed. Good sanitation is practiced during harvest, packing, transport, and storage.

Chemical.

Though protective, broad-spectrum fungicides are available for use to control Mucor fruit rot, they are rarely used to target this disease. Treatments are made before the advent of cool to warm, moist weather after fruit set has begun.

Captan. 0 day PHI. Captan is a N-trihalomethylthio fungicide applied at an average rate of 2 lb ai per acre. Captan is applied to 100% of the strawberry acreage several times to treat several fungal diseases. It is not applied in combination with or immediately following application of spray oils. The restricted entry interval is 24 hours.

Thiram. 3 day PHI. Thiram is a dithiocarbamate applied at an average rate of 2 lb ai/acre and was applied to 70% of strawberry acreage in 2000. The primary target of these applications is the control of Botrytis. The average number of annual applications of thiram on a field is 2. It is not applied in combination with or immediately following pplication of spray oils. The restricted-entry interval for thiram is 24 hours.

ANGULAR LEAF SPOT
Xanthomonas fragariae

Damage. The adverse impacts of angular leaf spot are increasing. The disease is a severe problem in all nursery locations and is becoming more of a problem in fruit production regions such as the central and south coast. The disease is favored by cool, moist days with cold nights near freezing. Infection first appears as minute, water-soaked spots on the lower surface of leaves. The lesions enlarge to form translucent, angular spots that are delineated by small veins and often exude viscous ooze, which appears as a whitish and scaly film after drying. As the disease progresses, lesions coalesce and reddish brown spots, which later become necrotic, appear on the upper surface of the leaves. A chlorotic halo usually surrounds the infected area.

Description of Disease. This bacterium is not free living in soil. It can, however, overwinter in soil on previously infected plant material. Transmission is by splashing water. It is host specific and highly resistant to degradation. The disease can persist in the soil for long periods of time. Methyl bromide/chloropicrin mixture used as a preplant fumigant kills the fungus, so it is very likely that most initial infections in fields that have been fumigated originate from contaminated plants. Lesions on the leaf surface serve as a source for secondary inoculum and cells are dispersed by rain splash or overhead irrigation. Although uncommon in California, *Xanthomonas fragariae* can cause vascular collapse and can be confused with phytophthera crown rot and root rot, *Colletotrichum* crown rot and Verticillium wilt. This symptom initially appears as a water-soaked area at the base of newly emerged leaves. Shortly after, the whole plant suddenly dies, much like plants infected with crown rot.

CONTROLS

Cultural

Sanitation. Growers use certified clean planting stock though the certification system has become less reliable in recent years.

Drip Irrigation. Growers avoid overhead irrigation whenever possible. Drip irrigation and other limited water programs can be effective in reducing spread of the disease.

Biological

There are no specific biological control methods for angular leaf spot.

Chemical

Chemical controls are typically ineffective against this pathogen.

Methyl Bromide/Chloropicrin. Methyl Bromide with Chloropicrin is applied as a pre-plant soil fumigation to fields at a combined rate of 300 to 400 lbs/acre. It is applied to essentially all of California's production and nursery acreage. Methyl bromide use is highly restricted and will be phased out by 2005, with a 70% reduction by 2003. There are numerous restrictions on the application of this restricted-use pesticide.

Fixed Copper. 1 day PHI. Fixed Copper is applied at label rates to less than 10% of strawberry acreage. Copper can be phytotoxic to plants with repeat applications. The restricted-entry interval for fixed copper is 24 hours.

RED STELE
Phytophthora fragariae

Damage. Red Stele is not as important in California as it is in Eastern growing regions due to soil fumigation, raised beds, drip irrigation and lower rainfall. However, it is expected to increase as methyl bromide is phased out. The symptoms of this disease include severe stunting followed by death of plants. Optimum conditions for disease development occur when the soil is saturated. Zoospores (motile spores) swim to the roots and infect them. The well-drained soil and warmer soil temperatures of California's growing regions reduce and delay disease development. As a result, Red Stele represents only about 5% of the economic impact of phytophthora-based diseases in California. The incidence of this disease is expected to increase with the phase out of methyl bromide and the increased use of opaque mulches for weed control but which also reduce soil temperature.

Description of Infection. Symptoms first appear in plants located in low, poorly drained parts of the field. Plants become stunted as older leaves die and are replaced by smaller, younger leaves with short petioles. Young lateral roots are often completely rotted. New crown roots die from their tips back, producing a symptom called "rat tail". Splitting the root reveals the red stele from which the disease gets its name.

CONTROL

Cultural

Moisture Limitation. Growers plant strawberries on raised bed, use carefully managed drip irrigation, good soil drainage, and keep soil pH up to at least 7.

Biological

There are no specific biological control agents against Red Stele.

Chemical

Methyl Bromide/Chloropicrin. Methyl Bromide with Chloropicrin is applied as a pre-plant soil fumigation to fields at a combined rate of 300 to 400 lbs/acre. It is applied to essentially all of California's production and nursery acreage. Methyl bromide use is highly restricted and will be phased out by 2005, with a 70% reduction by 2003. There are numerous restrictions on the application of this restricted-use pesticide.

Mefenoxan. 1 Day PHI. Mefenoxam (RIDOMIL GOLD) is a purer form of the active isomer of metalaxyl (RIDOMIL) and has replaced use of metalaxyl. Mefenoxam is applied at 0.5 lb a.i./acre an average of one time per season. In 2000, 12% of the strawberry acreage was treated. The restricted-entry interval is for mefenoxam is 48 hours.

Fosetyl-Aluminum. 0.5 day PHI. Fosetyl-al (ALIETTE) is used as a preplant dip (2 lbs/100 gal) or applied at 2-4 lbs a.i./acre to affected areas to slow the progress of the disease. Fosetyl-al was applied to about 16% of strawberry acreage in 2000. The restricted-entry interval is 12 hours.

WEEDS

Overview. The longer growing season of California strawberries results in a greater challenge to weed control. Effective weed management in strawberries requires a combination of cultural practices, preplant soil fumigation, and additional herbicide applications when necessary. Proper preplant field preparation and bed preparation are essential for a good weed control program. For weed control, soil fumigation with a combination of methyl bromide and chloropicrin, or to a lesser extent metam sodium, in conjunction with plastic mulches, is a major method of weed control in California strawberries. A few growers in the warm Central Valley use soil solarization in place of preplant fumigation. For weeds that escape preplant controls, hand-weeding and/or selective herbicides are used. In some cases, organic mulches have been used instead of plastic ones.

Strawberries are highly susceptible to weed competition immediately after planting when the plants are small and frequent sprinkling provides ideal conditions for weed germination. Most weeds that invade strawberries are annuals. During stand establishment, little mallow bur, clover and sweet clover, and filaree are common weeds because their seeds survive fumigation. Once strawberries are in the bearing stage of growth, windblown weed seeds including sowthistle, common groundsel, and grasses may become problems. In certain sites, perennial weeds such as field bindweed, spurge, and bermudagrass may require control, especially in fields where the crop is carried over into a second year of production. In areas where strawberries are carried over for 2 years, weed management during the second winter consists of a combination of preemergence herbicides, mulches, and/or hand-weeding.

Growers select sites with good drainage in areas with good quality water. Fields are surveyed for perennial weeds. The broad-spectrum control of methyl bromide allows for the use of land that may have a weedy history, but less weedy sites are preferred. Certain weeds (such as hairy nightshade) host soil-borne diseases (such as Verticillium wilt). Treatment of these weeds, therefore, can result in a lower incidence of soil-borne diseases. During the early stages of plant establishment, growers must check frequently for weeds (at least once every 3 weeks during the first 3 to 4 months after planting). Weeding crews are sent through fields, as needed, to remove weeds.

The loss of methyl bromide in 2005, with incremental reductions of 50% in 2001, and 70% in 2003, will have a dramatic impact on the effectiveness of weed control on California strawberries. Productivity losses are anticipated due to increasing competition for soil and sun and increased abundance of hosts for insect pests and diseases. Alternative fumigants, such as 1,3-dichloropropene plus chloropicrin mixture (TELONE C-35) and chloropicrin alone, are less active on weeds than methyl bromide. Therefore, weeding costs are likely to increase during and after the methyl bromide phase out.

CONTROLS

It is important to note that all discussion related to weed control are based on pest management strategies utilizing certified pest/disease free nursery stock growing in soil treated with methyl bromide/chloropicrin.

Cultural

Weeds can be controlled culturally through the use of hand weeding or with organic and synthetic mulches.

Hand Weeding. During the early stages of plant establishment, mechanical removal, by hand pulling, is the most practical means for control. Timely removal of weeds is essential to minimize competition.

Mulches, Organic. If leaves are pruned during the winter, organic mulches are sometimes applied at this time to suppress weed infestation. To control weeds effectively, at least 2 inches of mulch is necessary and must be maintained to keep weeds from growing through the mulch. Organic mulches may increase problems with snails, slugs, earwigs, and possibly other insects. Examples of organic mulches include wood shavings, chopped straw, and rice hulls.

Mulches, Synthetic Opaque. Synthetic mulches are usually some type of opaque plastic. These may be brown, black, or white, but they must restrict light from penetrating the film to be effective. Some of the darker color mulches can result in yield losses, particularly in the south coast growing regions. For example, dark mulches such as brown, black and green mulches can reduce yields by 10% to 15% in the south coast regions. Opaque mulches can be an effective method of weed control. Weed growth is greatly reduced with opaque mulches, but weeds still grow in the hole where the strawberry plant is and need to be removed by hand. Opaque mulches do not heat the soil sufficiently for early fruit production and high yields.

Solarization with Mulches, Synthetic Clear. On the central coast, solarization requires at least 12 to 15 weeks in order to obtain pest management benefits; consequently, solarization is not a practical substitute for fumigation on the coast. The effectiveness of solarization is much better in areas of the state where temperatures are consistently hot in summer, such as the San Joaquin Valley. In South Coast winter plantings, clear plastic mulches are commonly used to promote early harvest. Clear plastic serves as a greenhouse to encourage early strawberry growth. Unfortunately, viable weed seeds in the strawberry beds will also germinate in the warm soil and grow under the plastic. Therefore, it is critical that an effective fumigant be used that eliminates all viable weed seeds in the upper 2 inches of the planting bed. Once the mulches are in place, controlling weeds below them is difficult and time consuming.

Mechanical Weeding. Weed seed reservoirs can be reduced by off-season growth and mechanical removal, however, this practice is not practical in many of the growing regions within the state and is rarely, if ever practiced. Following bed formation, growers can sprinkler irrigate to germinate weeds, thus reducing the weed seed reservoir in the soil. Irrigation is followed with timely removal of weed growth with minimal soil disturbance. Cultivation equipment is used for furrows, but the sides and tops of beds must still be hand-weeded. Hand weeding is the most practical means of weed control.

Because most California strawberries are planted in the fall-winter period, this practice is accomplished in mid-to-late summer. This works well in coastal climates where soil temperatures are usually cool enough for winter weeds to germinate year round. In the interior valleys with warmer climate, winter annuals may not germinate during this period and mechanical weeding is not effective.

Chemical

For effective weed seed control it is essential, regardless of fumigant, that the soil be pre-irrigated so that weed seeds are saturated with water before fumigation and that soil temperatures be above 55°F. The following fumigants are used for weed control.

Methyl Bromide/Chloropicrin. Methyl Bromide with Chloropicrin is applied as a preplant fumigation to fields at a rate of 300 to 400 lbs/acre to control weeds and other soil-borne pests. This combination is currently applied to essentially all of the production and nursery acreage in the state. Soil fumigation must be performed at least 14 days before planting. This time period may vary with soil temperatures and dosage rates. Methyl bromide is being phased out and will no longer be available in 2005, with a 70% reduction by 2003. Weed control will be much more difficult without this effective, extremely broad-spectrum herbicide. Herbicide substitutes are not available to substitute for the spectrum of methyl bromide efficacy. . There are numerous restrictions on the application of this restricted-use pesticide.

Metam Sodium. Metam sodium is applied as a preplant fumigant to less than 1% of treated fields. Metam-sodium is an effective material provided it comes in contact with the target organism. Metam-sodium, a liquid at atmospheric conditions, is applied by several methods: it can be injected into sprinkler systems, shanked into soil and tarped, or water-run with drip tape systems. It is not a direct substitute for methyl bromide and different application techniques are needed to obtain optimum results. Metam sodium is a restricted use material and may only be applied by permit from a county agricultural commissioner. Soil fumigation must be performed at least 14 days before planting. This time period may vary with soil temperatures, dosage rates, type of tarp, and soil type. There are numerous restrictions on the application of this restricted-use pesticide.

With the current primary role of fumigants for weed control and the widespread use of plastic mulches, conventional herbicides are often used less frequently than in many other crops. Postemergence herbicides are ineffective due to the common use of plastic mulches that prevent the herbicide from contacting the weeds growing under the plastic mulch.

Napropamide. Pre-bloom. Napropamide (DEVRINOL) is a pre-emergent herbicide applied at a rate of 4 lbs ai per acre and was applied to 6% of strawberry acreage in 2000. It may be applied at transplanting or during the early stage of strawberry development. It is applied to the soil and must be incorporated with 7 days of application with sufficient rainfall or sprinkler irrigation. Napropamide is effective on little mallow and filaree if applied before the weeds have emerged. If the application is delayed to establish plantings, emerged weeds must be removed before application. The use of napropamide can delay maturity and result in 10% to 20% yield reductions, although this is not typically seen in banded bed fumigation. The residual period is 4 to 10 months. The restricted entry interval is 12 hours.

Paraquat Dichloride. 21 day PHI. Paraquat dichloride (GRAMOXONE) is a post emergent herbicide used on 8% of the strawberry acreage in 2000 at an average rate of about 0.65 lb ai per acre. Paraquat is often used to target weeds in furrow bottoms. The restricted-entry interval for paraquat dichloride is 12 hours.

Sethoxydim. 7 day PHI. Sethoxydim (POAST) is a post-emergent herbicide applied to much less than 1% of the strawberry acreage. Sethoxydim is effective only on grass weeds (except annual bluegrass). Annual bluegrass is the only major grass weed in strawberries on the Central Coast, therefore, sethoxydim is not widely used. The restricted-entry interval is 12 hours.

The following active ingredients are not currently registered for strawberries but are needed tools as soon as possible. An expedited registration is encouraged by the industry.

Clopyralid. Clopyrilid (STINGER) is an effective broad-leaf weed herbicide not currently registered but scheduled for EPA review in 2001 or 2002..

Clethodim (SELECT) registration is anticipated some time in 2002.

Flumioxazin is an effective broad-leaf weed herbicide not currently registered.

Oxyfluorfen (GOAL) is an effective broad-leaf and grass weed herbicide not currently registered.

VERTEBRATE PESTS

Overview. A number of vertebrate species may move into or live near strawberry fields that seek the fields for food. The potential for damage by vertebrates varies from field to field and region to region. Some fields are much more susceptible to damage. Migratory and resident birds can cause significant damage. Fields located near rangeland, wooded areas or other uncultivated areas are more likely to be invaded or re-invaded by certain vertebrates. Predators, diseases and food sources all may influence vertebrate populations. Predators such as coyotes, foxes, snakes, hawks and owls feed on rodent and rabbit species. Growers cannot, however, rely on predators to prevent rodents or rabbits from becoming agricultural pests.

BIRDS

HOUSE FINCH: *Carpodacus mexicanus*
ROBIN: *Turdus migratorius*
GOLDFINCHES: *Carduelis* spp.
CEDAR WAXWING: *Bombycilla cedrorum*
STARLING: *Sturnus vulgaris*
LONG-BILLED CURLEW: *Numenius americanus*

Damage. Several species can cause severe damage when they feed on ripening fruit in strawberry fields. Economic losses can be reduced by frightening devices or preventing access during the harvest season by placing netting over the field.

House finches are the most troublesome bird pest in strawberries. They are residents in all strawberry growing regions and may feed in strawberry fields whenever ripe fruit is present.

Robins are present in strawberry fields throughout the year in some parts of southern California. In other regions, flocks of robins visit fields during migration, usually in late winter or early spring.

Goldfinches are small, bright yellow birds that typically feed on weed seeds, but in fall or in late winter large flocks may invade strawberry fields to feed on the seeds of the strawberry fruit.

Cedar waxwings are shiny, buff brown birds that have a characteristic crest and black mask over the eyes. They may cause serious damage to strawberry production in the central coast region. Cedar waxwings move through fields in flocks of 20 to 50 birds during late winter and early spring migrations, destroying large quantities of ripening fruit.

Starlings, in large migratory flocks, may invade strawberry fields in late winter or early spring to feed on ripe strawberries. Resident starlings may feed in strawberry fields any time ripening fruit are present.

Long-billed curlews move through fields on the central coast, Santa Maria Valley and Oxnard Plain regions in early spring. They are large birds with a wingspan of about 2 feet, that have long legs and are characterized by a long bill that curves downward at the tip. Curlews feed in flocks of 10 to 20 and tend to return to the same areas each spring.

Monitoring. The best strategy for reducing bird damage depends on the species feeding on the crop. Growers identify the birds that are causing damage before choosing controls. By keeping records of bird problems and the time of year they occur, helps growers to plan control actions.

CONTROL

Cultural

Visual Frightening Devices. Mylar stake flags are placed in fields to frighten away house finches. Visual frightening devices, such as mylar stake flags or large-eye balloons can also be used to reduce damage from robins and cedar waxwings. These visual repellents only reduce damage from goldfinches temporarily.

Noisemakers. Curlews are usually easily frightened. Noisemakers, such as shell crackers fired from shotguns are an effective control for this bird. For cedar waxwings and starlings, noisemakers can be effective if more than one kind is used. Because cedar waxwings and starlings quickly become accustomed to one type of noise, a combination of noisemakers (such as propane exploders, bird bombs, and shell crackers) is necessary to achieve control. Growers start using noisemakers as soon as the birds begin feeding in the field. Goldfinches are difficult to frighten with noisemakers. Noisemakers are not effective against house finches.

Traps. When the house finch population is high, trapping is an effective alternative, but may only be done with permit from the U.S. Fish and Wildlife Service. Starlings are also trapped in modified Australian crow traps or converted cotton trailers placed near feeding or roosting sites.

Plastic Netting. Plastic netting placed over the crop is the most effective means of preventing damage from house finches, goldfinches, and cedar waxwings.

Shooting Prohibitions. Cedar waxwings are protected, therefore, they may not be shot. Shooting to scare or kill may be used for starlings, an unprotected species, since shooting increases the effectiveness of other noise making devices when done occasionally.

CALIFORNIA GROUND SQUIRREL
Spermophilus beecheyi

Damage. Ground squirrels can be a serious problem in strawberry fields when populations have built up in adjacent areas and invade the fields to feed on fruit. Squirrels may also feed on leaves and stems and sometimes damage polyethylene irrigation hoses.

Monitoring. Growers monitor for ground squirrels by checking the perimeter of the field about once per month for animals or their burrows. If monitoring indicates that a squirrel population is moving in, they can be controlled with traps, fumigants, or toxic bait.

CONTROLS

Cultural

Traps. Trapping ground squirrels works well in small areas or for a small number of squirrels. Growers check the traps daily. Ground squirrels are classified as nongame mammals and can be eliminated at any time if injuring crops. Tree squirrels, however, are classified as game mammals by the California Fish and Game Code and a permit from the local game warden is required for control of the eastern gray squirrel and poisoning of this tree squirrel is illegal. The eastern fox squirrel may also be eliminated in any manner if causing damage.

Chemical

Strychnine. Strychnine bait is applied at label rates to control ground squirrels. Baiting by hand is one of the most effective control mechanisms. Single dose baits can also be placed in traps and in burrows though this is an ineffective control method. Strychnine is rarely used by the strawberry industry since the baits are usually less attractive than the strawberry fruit.

Aluminum Phosphide. Aluminum phosphide is a phosphide fumigant that is used to control burrowing rodents. It works best in early spring when moist soil helps retain a high toxic gas level in the burrows. The burrows are checked after about three days. Where squirrels have dug out, retreatment is necessary. It is rarely used on strawberry acreage.

Diphacinone. Diphacinone is an anti-coagulant rodenticide bait intended to control ground squirrels. It is applied at labeled rates to traps or in bait stations. Baiting by hand is one of the most effective control mechanisms. Single dose baits can also be placed at intervals in the main tunnel. Diphacinone is a restricted use material that may only be applied with permit from a county agricultural commissioner. It is rarely used.

Zinc Phosphide. Zinc phosphide is a bait used to treat ground squirrels. It is rarely used in California.

MEADOW MICE
Microtus spp.

Damage. Meadow mice, which are also referred to as voles or field mice, inhabit roadsides, meadows, canal banks, fence-rows and many field crops. When mouse populations reach high levels in their native grassy habitats, they invade and occupy neighboring strawberry fields, feeding on ripening fruit.

Description. Full-grown meadow mice are larger than house mice but smaller than rats. Well-established populations can be recognized by the network of small runways through the grass or other cover and the openings of numerous shallow burrows. Meadow mice are active year round, day and night.

Monitoring. Growers monitor the fields by visually inspecting fields looking for active runways and burrows. Snap traps baited with a mixture of peanut butter and oats are also used to monitor the mouse populations.

CONTROL

Cultural

Eliminate Habitats. Preventative measures are taken by growers to eliminate favorable mouse habitats adjacent to strawberry fields. Growers clear weeds along fence lines, field margins and irrigation and drainage ditches.

Eliminate Pest. Meadow mice are classified as non-game mammals and may be eliminated in any manner at any time if they are injuring crops.

Chemical

Diphacinone. Diphacinone is an anti-coagulant rodenticide bait applied at labeled rates. Baiting by hand is one of the most effective control mechanisms. Single dose baits can also be placed at intervals in an active runway, or burrow entrance. Diphacinone is rarely used in strawberries.

Zinc Phosphide. Zinc phosphide is a bait used to treat meadow mice at labeled rates. Zinc phosphide is not used in California strawberries.

MOLES
Scapanus spp.

Damage. Moles may invade strawberry plantings anytime during the year, destroying planting beds with their burrowing activity. Moles feed primarily on earthworms and soil arthropods, which are destroyed by soil fumigation; therefore, moles are more likely to invade second-year and nonfumigated strawberry fields. Moles construct shallow feeding tunnels, which are apparent as linear ridges on the soil surface, and a serious of deeper tunnels from which soil is pushed to the surface to form molehills. Molehills tend to be circular with a plug in the middle.

Description. Moles have cylindrical bodies with pointed snouts, dark, velvety fur, and spadelike front feet used for digging. They are active day and night and are rarely seen above ground.

CONTROL

Cultural

Traps. Moles are controlled by placing traps in or above tunnels. Traps placed in deeper tunnels are more effective because moles typically continue using deeper tunnels, whereas some surface tunnels are temporary.

MULE DEER
Odocoileus hemionus

Damage. In northern California, mule deer sometimes enter nursery fields destroying young strawberry plants by feeding on them and trampling them. They feed on plants and fruit, in fruit production fields located near good deer habitat. Deer are most likely to be a problem from late spring to midsummer in low-elevation nurseries. Deer feed at night and early in the morning. Growers identify deer pests by footprints in the field and deer droppings.

CONTROL

Cultural

Barriers. Growers erect deer-proof fences, 7 feet high. A six-foot mesh fence with several strands of smooth or barbed wire on top is most effective. Fences must be kept tight to the ground as some deer will crawl under the fencing to feed in the field. When only a few deer are involved, it may be economical and effective to have someone patrol the field with a spotlight to frighten the deer away.

Eliminate Pest. Depredation permits may be obtained from the California Department of Fish and Game to eliminate a few animals. This is a temporary solution, but may prevent further damage while a fence is being constructed.

RESEARCH

With the impending loss of methyl bromide as a pest management tool, the strawberry industry faces the challenge of developing a sound, multi-faceted, reduced-risk approach to integrated pest management that will provide viable biological controls, cultural practices and chemical tools for disease, insect and weed control. The continued economic success of the strawberry industry in California will be based, in part, on the industry's ability to develop a pest management program that balances sound cultural and biological control practices with chemical treatment.

Research and development into alternate pest management systems that can substitute for the current uses of methyl bromide is clearly the number one future challenge and focus of the industries research efforts. Methyl bromide will no longer be available for use in 2005 and there are no comparable broad-spectrum tools available for control of soil-borne pests. Alternates to methyl bromide being assessed currently include the fumigants chloropicrin (alone), metam sodium, and 1,3-dichloropropene plus chloropicrin (TELONE C-35); however, substantial regulatory impediments exist for use of these methyl bromide alternatives. Chloropicrin alone is not permitted in certain counties within California. Metam sodium is under FQPA review by the United States Environmental Protection Agency and 1,3-dichloropropene is limited by township caps.

Narrow spectrum chemical tools are also being tested to substitute for parts of the wide array of pest control solutions that methyl bromide currently provides. For example, pesticides such as hexythiazox (SAVEY) may substitute for some of the miticidal properties of methyl bromide and herbicides may enhance the weed control activity of the methyl bromide alternatives. Examples of new soil-applied herbicides that may be used for this purpose are: carfentrazone-ethyl, flumioxazin, isoxaben and sulfentrazone. In areas where plastic mulches are not used, a post emergence herbicide, triflusulfuron, may be a useful treatment to explore. The development of a glyphosate resistant strawberry will be of limited value in California due to the extensive use of plastic mulches that prevent glyphosate application to weeds growing below the plastic.

Enhanced use of cultural techniques such as mulching, solarization and plant breeding are also being considered by the strawberry industry. It is clear that, for California's strawberry industry, many different chemical and cultural tools will be needed in the near future to substitute for this single pest management ingredient.

Other areas of particular research needs are the development of control methods for Lygus bugs, Western Flower Thrips, and mites. Diseases of increasing concern to the industry include Verticillium wilt, phytophthora crown rot and root rot, and red stele though significant increases in the resistance of Botrytis fruit rot to existing fungicides has triggered increasing research into new pest management tools and expanded use of IPM by the industry.

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CONTACT PERSONS

Janice K. Sharp, Ph.D. (Overall Pest Management Contact)
California Strawberry Commission
180 Westridge Drive, Suite 101
PO Box 269
Watsonville, California 95077-0269
831-724-1301 ext. 149
jsharp@calstrawberry.org

Doug Gubler (Foliar Diseases)
Department of Plant Pathology
University of California at Davis
Davis, California 95616
530-752-4982
wdgubler@ucdavis.edu

John Duniway (Soil Borne Disease)
Department of Plant Pathology
University of California at Davis
Davis, California 95616
530-752-0324
jmduniway@ucdavis.edu

Steve Fennimore (Weeds)
Weed Science Program, Department of Vegetable Crops
University of California at Davis
c/o USDA
Salinas, California 93905
831-755-2896
safennimore@ucdavis.edu

Frank Zalom (Entomology)
UC Statewide IPM Program
University of California at Davis
Davis, California 95616
530-752-8350
fgzalom@ucdavis.edu

Nick Toscano (Entomology)

University of California, Riverside
Riverside, California
909 787-5826
nick.toscano@ucr.edu

Becky Westerdahl (Nematodes)
Department of Nematology
University of California at Davis
Davis, California 95616
530-752-1405

Kirk Larson (Pomology)
Department of Pomology
University of California at Davis
Davis, California 95616
949-857-0136
kdlarson@ucdavis.edu

Doug Shaw (Pomology)
Department of Pomology
University of California at Davis
Davis, California 95616
dvshaw@ucdavis.edu

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Appendix B.

Technical Meetings and Field Days

January 8, 2001

Annual Strawberry Research Conference

February 7, 2001 8: 30 AM – 3: 30 PM
Arts Building, Santa Cruz County Fairgrounds
2601 East Lake Avenue, Watsonville, California

CONFERENCE AGENDA

8:30	Registration (no fee required)
9:00	Regulatory Update Mr. Dave Moeller, Ag. Commissioner, Santa Cruz County
9:30	Commission Activities Update California Strawberry Commission
10:00	Breeding and Cultural Practices Update Dr. Douglas Shaw, Professor & Geneticist, UC Davis
10:30	Mites and Thrips: Little Creatures, Big Issues Dr. Frank Zalom, CE Entomology Specialist & Director, UCIPM, UC Davis
11:00	Break
11:30	Breeding and Bronzing Update Dr. Kirk Larson, Pomologist, UC Davis
12:00	Control of Botrytis Fruit Rot Dr. Doug Gubler, Plant Pathologist, UC Davis
12:30	Lunch
1:30	Verticillium Biology and Management Dr. Tom Gordon, Plant Pathologist, UC Davis
2:00	Current/Future Alternatives for Methyl Bromide Dr. John Duniway, Professor & Plant Pathologist, UC Davis
2:30	Phytophthora Management Update Dr. Greg Browne, Plant Pathologist, UC Davis
3:00	Strawberry Weed Control Without Methyl Bromide Dr. Steve Fennimore, CE Weed Specialist, UC Davis
3:30	Adjourn

Spanish Translation will be Provided
CE Credits Requested

January 8, 2001

Simposium de Investigación en Fresa

7 de febrero, 2001 8: 30 AM – 3: 30 PM

Edificio de Arte (Arts Building), Santa Cruz County Fairgrounds

2601 East Lake Avenue, Watsonville, California

No hay costo para asistir a la conferencia. Habrá almuerzo para participantes que paguen $10.00 que se registren en adelanto. Para más información, sírvase comunicar con la California Strawber Commission, 831-724-1301.

PROGRAMA

8:30	Registro (sin pago)
9:00	Resumén Regulatorio Sr. David Moeller, Ag. Commissioner, Santa Cruz County
9:30	Resumén de Actividades de la Comisión California Strawberry Commission
10:00	Resultados de Investigación en Mejoramiento Genético y Producción de la Fresa Dr. Douglas Shaw, Professor & Geneticist, UC Davis
10:30	Ácaros y Trips: Pequeñas Plagas de Gran Importancia Dr. Frank Zalom, CE Entomology Specialist & Director, UCIPM, UC Davis
11:00	Pausa
11:30	Resultados de Investigación en Mejoramiento Genético y Fisología de la Fresa Dr. Kirk Larson, Pomologist, UC Davis
12:00	Control de Pudrición de la Fruta Causada por el Hongo Botrytis Dr. Doug Gubler, Plant Pathologist, UC Davis
12:30	Almuerzo
1:30	Biología y Control de Verticillium en Fresa Dr. Tom Gordon, Plant Pathologist, UC Davis
2:00	Posibles Alternativas al uso de Bromuro de Metilo en Fresa Dr. John Duniway, Professor & Plant Pathologist, UC Davis
2:30	Resultados de Investigación en Biología y Control de Phytophthora Dr. Greg Browne, Plant Pathology, UC Davis
3:00	Control de Malezas en Fresa sin Bromuro de Metilo Dr. Steve Fennimore, CE Weed Specialist, UC Davis
3:30	Fin

Traducción a Español Disponible para Participantes

Se ha solicitado 6 unidades de crédito "CE" para participantes.

Strawberry Field Day
University of California South Coast R.E.C., Irvine
8:30 am – 3:00 pm, March 14, 2001

8:00 Set-up posters, etc. (tractor barn)

8:30 Registration

9:00 Introduction, K. Larson and D. Shaw

9:15 Transport to field

9:30 Field Day
- a) K. Larson – 1 hour, breeding, cultural practices, fumigation alternatives
- b) D. Shaw – 20 minutes, breeding and cultural practices
- c) F. Zalom – 15 minutes, strawberry arthropod IPM (mites, white-fly, thrips)
- d) J. Duniway – 10 minutes, fumigation alternatives

11:15 Leave field

11:30 Lunch and speakers (Tent)
- a) D. Riggs (5-10 mins) CSC update
- b) J. Sharpe (5-10 mins) Pesticide regulatory issues update
- c) D. Gubler (5-10 mins) Fungicide update, biology and management of Anthracnose Crown/Fruit Rot
- d) H. Ajwa (5-10 mins) Drip applied fumigation
- e) J. Duniway (5-10 mins) Soil borne pest control with chemical and nonchemical fumigation alternatives
- f) S. Fennimore (5-10 mins) Weed control with fumigation alternatives

12:30 Visit posters and discuss research issues:

Shaw	Ajwa	Gordon
Larson	Duniway	Browne
Gubler	Fennimore	Bendixen
Zalom	Winterbottom	Koike

3:00 End

The California Strawberry Industry Welcomes You to the

OXNARD STRAWBERRY FIELD DAY

at Martinez Berry Farms, 3478 E. Hueneme Road
Oxnard, California

Thursday, March 29, 2001

Farm Map Location	Time	Event
1	9:00 a.m.	Registration - Pick up Information Packets
2	9:30	Welcome - David Riggs, California Strawberry Commission
2	9:40	Regulatory Update, Jan Sharp, California Strawberry Commission
2	9:50	Parameters in Drip Applied Fumigants, Husein Ajwa, USDA/ARS
3	10:00	Efficacy of Methyl Bromide Alternatives Against *Verticillium* John Duniway, UC Davis
3	10:10	Efficacy of Methyl Bromide Alternatives Against *Phytophthora* Greg Browne, UC Davis
3	10:20	Efficacy of Methyl Bromide Alternatives Against 'Root Nibblers' (*Phythium*, etc.) Frank Martin, USDA/ARS
4	10:30	Weed Control with Methyl Bromide Alternatives Steve Fennimore, UC Davis
5	10:40	Farmer Experience with Methyl Bromide Alternatives Cecil Martinez, et al.
6	11:40	New Cultivar Update, Kirk Larson, South Coast Research and Extension Center
7	12:00 p.m.	BBQ Lunch with Poster Session
7	12:20	Fungicide Update, Doug Gubler, UC Davis
7	12:30	Miticide, Whitefly and Other Pests Update Frank Zalom, UC Davis, Nick Toscano, UC Riverside
7	12:40	Economic Effects of the Methyl Bromide Phase-out, CDPR Buffer Zones Colin Carter, UC Davis
	1:00	Adjourn

Spanish Translation will be provided – 4.5 CE Credits have been granted for this event.

California Strawberry Commission, P.O. Box 269, Watsanville, CA 95077-0269
Phone (831)724-1301/ Fax (831)724-5973, www.calstrawberry.com

March 22, 2001

2001 Santa Maria Strawberry Field Day
Tuesday, April 10, 2001
8:30 a.m. to 2:00 p.m.

Location: Gold Coast Farm – Ron Burk
0.4 miles East of Highway 101 on Stowell Road

8:30 a.m.	Registration
9:00 a.m.	Introduction: Warren E. Bendixen, Farm Advisor, Santa Barbara County
9:10 a.m.	Strawberry Production on Gold Coast Farms, Ron Burk, Manager, Gold Coast Farms
9:20 a.m.	New Methyl Bromide Regulations, Bill Gillette, Ag. Commissioner, Santa Barbara County
9:40 a.m.	California Strawberry Commission Update, Dave Riggs, California Strawberry Commission
10:00 a.m.	Production Practices, Warren E. Bendixen, Farm Advisor, Santa Barbara County
10:20 a.m.	Verticillium Biology and Management, Tom Gordon, Plant Pathologist, U.C. Davis
10:40 a.m.	Phytophthora Management Update, Greg Browne, Plant Pathologist, USDA/ARS, Davis

Location: DB Specialty Farms – Daren Gee
0.9 miles East of 101 on Stowell Road and 0.5 miles North on Rosemary Road

11:30 a.m.	Strawberry Production at DB Specialty Farms, Daren Gee, Manager, DB Specialty Farms
11:40 a.m.	New Strawberry Varieties and Pomology Research Update, Kirk Larson and Douglas Shaw, U.C. Davis, Pomology Department.
12:20 p.m.	BBQ Lunch – California Strawberry Commission
1:10 p.m.	Control of Strawberry Foliar Diseases, Doug Gubler, CE Pathology Specialist, U.C. Davis
1:30 p.m.	Fumigation with Methyl Bromide and Alternatives, Christopher Winterbottom, California Strawberry Commission
2:00 p.m.	Adjourn

Spanish Translation will be Provided – CE Credits have been requested.
Habra traducción en español disponible

June 18, 2001

REMINDER NOTICE

Monterey Bay Academy Strawberry Research Field Day

The annual Monterey Bay Academy field day is an excellent opportunity for farmers to see and discuss work being conducted by UC and USDA researchers in methyl bromide alternatives research, organic and conventional IPM strawberry production systems.

Date:	Wednesday, June 27, 2001
Time:	9 a.m. – 12:20 p.m.
Location:	Monterey Bay Academy (3 miles north of West Beach Road on San Andreas Road)

Research in Organic Strawberry Production Systems

9:00 a.m.	**Carolee Bull**, USDA/ARS Salinas - Effect of cultivar and commercial mycorrhizal inoculates on organic strawberry production
9:20	**Frank Martin**, USDA/ARS Salinas - Influence of crop rotation on management of soilborne diseases in strawberry production
9:40	**John Duniway**, UC Davis - Cultural practices for management of Verticillium Wilt

Research in Conventional IPM Strawberry Production Systems

10:00	**John Duniway**, UC Davis - Alternatives to methyl bromide, some chemical, cultural and biological approaches
10:20	**Cynthia Eayre**, USDA/ARS Fresno - Chloropicrin by PGPR interaction in strawberry production
10:40	**Doug Gubler**, UC Davis - Foliar disease control
11:00	**Greg Browne**, USDA/ARS Davis - Strategies for *Phytophthora* management
11:20	**Frank Martin**, USDA/ARS Salinas - Influence of general root pathogens such as *Pythium* and *Rhizoctonia* on plant growth and yield
11:40	**Husein Ajwa**, USDA/ARS Fresno - Strawberry response to fumigants applied by drip irrigation
12:00	**Steve Fennimore**, UCCE Salinas - Strawberry weed control with alternative fumigants
12:20	Adjourn

3.5 PCA/CE credits have been granted for this field day. Traducciónes en español sera disponible. If you have any additional questions, please contact the California Strawberry Commission at (831) 724-1301

CALIFORNIA STRAWBERRY COMMISSION

The Pink Sheet

A Weekly Strawberry Production Newsletter

OFFICE: 831-724-0301 · FAX: 831-724-5973 · WWW.CALSTRAWBERRY.COM

June 21, 2001

Strawberry Research Field Day
USDA Agriculture Research Station, Salinas

Alternatives to Methyl Bromide, Strawberry Root Ecology and Organic Production

When: Tuesday, July 10, 2001; 9-12 AM

Where: USDA-ARS Spence Field site research plots located south of Salinas at the intersection of Old Stage and Spence Road (approximately 5 miles south of the USDA-ARS Research Station at 1572 Old Stage Rd.)

USDA-ARS and UC research scientists will explain their experimental plots and discuss ongoing research programs. Following a brief introduction each scientist will take approximately 20-30 minutes to discuss the following topics:

Drs. Husein Ajwa and Tom Trout, Water Management Research Laboratory, Fresno
Alternative chemicals for soil fumigation, alternative methods of chemical application (bed fumigation and application via the drip lines), and the influence of tillage, fertility and irrigation practices on yield.

Dr. Frank Martin, Crop Improvement & Protection Research Unit, Salinas
Evaluations of microbial inoculants on the growth and production of strawberry plants, variety trials in nonfumigated soil, the influence of crop rotation on soilborne pathogen populations and strawberry yield (done in collaboration with Dr. Krishna Subbarao of UC Davis and Steve Koike), and alternative chemicals for soil fumigation.

Dr. Carolee Bull, Crop Improvement & Protection Research Unit, Salinas
Evaluation of treatments to improve organic production. Evaluation of microbial biological control agents and biologically integrated farming systems on the growth and yield of strawberry plants.

Dr. Steve Fennimore, Dept. of Vegetable Crops & Weed Science, UC Davis, Salinas
Weed control efficacy of alternative fumigants (done in collaboration with Drs. Ajwa and Trout), evaluation of herbicides to provide supplemental weed control, and evaluation of ozone for weed control in organic strawberries.

Three hours of CE have been requested for this conference.
For questions contact Dr. Frank Martin at (831) 755-2873 or fmartin@asrr.arsusda.gov

The Pink Sheet

el 21 de Junio del 2001

Día de Campo de la Investigación de Fresa

En la Estación de Investigación de Agricultura del departamento de USDA en Salinas

Alternativas para Methyl Bromide, la ecología de raices de planta de fresa, y la producción orgánica

Cuando: **Martes el 10 de Julio del 2001**

Horario: **de 9 a.m. a 12 p.m.**

Lugar: **USDA-ARS sitio de experimentación en el campo en Spence localizado al sur de Salinas en la intersección de las calles Old Stage y Spence Rd. (Aproximadamente 5 millas al sur de la estación de investigación localizado en 1572 Old Stage Rd.)**

Científicos de la Universidad de California y del departamento de USDA-ARS explicaran sus plantíos de experimentación y hablaran acerca de los programas de investigación cual se encuentran en marcha. En lo siguiente encontrara una breve introducción de cada experimento y sus correspondientes científicos que tomaran aproximadamente 20-30 minutos para hablar sobre su tema:

Drs. Husein Ajwa y Tom Trout, Laboratorio de la investigación del manejamiento de irrigación, Fresno
Químicas alternativas para la fumigación de suelos, métodos alternativos para la aplicación de químicas (aplicación en cama y aplicación por medio del sistema de goteo), la influenza de cultivación y fertilidad, y practicas de irrigación en producción.

Dr. Frank Martin, El mejoramiento del cultivo y la Protección de la Unidad de Investigación, Salinas
Evaluación de inoculares microbiales en el desarrollo y producción de plantas de fresa, experimentos de variedades en suelos no fumigados, la influenza de rotaciones de cultivos en la población de patógenos de suelos y producción de fresa (este estudio es colaborado con Dr. Krishna Subbarao de UC Davis y Steve Koike), y químicos alternativos para la fumigación de suelos.

Dr. Carolee Bull, El mejoramiento del cultivo y la Protección de la Unidad de Investigación, Salinas
Evaluación de tratamientos para mejorar la producción organica. Evaluación del control biologico por medio de microbios y el sistema biológico integrado en el desarrollo y producción de plantas de fresa.

Dr. Steve Fennimore, Dept. de Vegetales y Ciencia de Malezas, UC Davis, Salinas
La eficiencia del control de malezas con fumigantes alternativos (este estudio es colaborado con Drs. Ajwa y Trout), evaluación de herbecidas para proveer control suplemental de malezas, y la evaluación de ozona para el control de malezas en fresas orgánicas.

Tres horas de CE han sido solicitadas para esta conferencia.
Para preguntas localice al Dr. Frank Martin al (831) 755-2873 o por email al fmartin@asrr.arsusda.gov

California Strawberry Commission P.O. Box 269 Watsonville, California 95077

The California Strawberry Industry Welcomes You to the

ANNUAL STRAWBERRY FIELD DAY AND RESEARCH CONFERENCE

at UC SCREC, 7601 Irvine Blvd., Irvine, CA

Wednesday, March 13, 2002

8:00 a.m. Registration/Coffee and Introductions

8:30 a.m. Introduction of special guests attending the 2002 Research Conference:
California Secretary of Agriculture Bill Lyons and CDPR Director Paul Helliker
Mr. Daren Gee, Research Committee Chairman, California Strawberry Commission

9:00 a.m. Pomology Research Program Activities Summary including discussion of new varieties and selections:
Dr. Kirk Larson, UC Davis at SCREC and Dr. Doug Shaw, UC Davis

9:30 a.m. Field Tour of strawberry integrated production system research plots including new varieties:

- Breeding, cultural practices and fumigation alternatives: Dr. Kirk Larson, SCREC, UC Davis
- Breeding and cultural practices: Dr. Doug Shaw, UC Davis
- Strawberry Arthropod IPM including mites, white-fly and thrips: Dr. Frank Zalom, UC Davis
- Fumigation alternatives: Dr. John Duniway, UC Davis
- Use/Efficacy Update: Dr. Doug Gubler, UC Davis

11:45 p.m. Barbecue Lunch

12:15 p.m. Strawberry Commission Report

- Commission Activities Update: Ms. Cindy Jewell
- Regulatory and Pesticide Update: Dr. Jan Sharp
- Review of Afternoon Presentations and Program: Dr. Beth Crandall

12:45 p.m. Poster Session and Exhibits – One-on-One Question and Answer Session with UC and USDA Scientists Funded by the California Strawberry Industry:

Dr. Husein Ajwa	Drip applied fumigants
Dr. Greg Browne	Strategies for management of *Phytophthora* on California strawberries
Dr. Colin Carter	Report on economic research on the California strawberry industry
Dr. John Duniway	Chemical and nonchemical fumigation alternatives
Dr. Steve Fennimore	Weed control with fumigation alternatives
Dr. Tom Gordon	Management of Verticillium Wilt
Dr. Doug Gubler	Botrytis and Powdery Mildew control
Dr. Bob Krieger	Harvester pesticide exposures: worker safety and risk management
Dr. Kirk Larson	Pomology project progress report
Dr. Doug Shaw	Pomology research summary: Davis and Watsonville
Dr. Frank Zalom	Statewide strawberry entomology project

2:00 p.m. Conclude

(See back for complete listing of UC and USDA scientists)

Appendix C.

Technical Handouts – Methyl Bromide Alternatives

Microbial Ecology of Strawberries

Dr. Carolee T. Bull, Research Plant Pathologist, USDA ARS
1636 East Alisal Street, Salinas, CA 93905-3018

My laboratory is designed to evaluate the ecology of microorganisms on plant surfaces and in the soil. We are particularly interested in cropping systems that will be effected by the loss of methyl bromide. Several of our projects have the potential to directly benefit California strawberry growers. In particular, we have made great progress this year working with grower cooperators to develop and test a biologically integrated production system for strawberries. In addition, we conducted fundamental research that is significant to the use of biological agents for controlling plant diseases.

1) **Development of a biologically integrated production system for strawberries.** The BASIS-OASIS program (Biological Agricultural Systems in Strawberries - Organic Agricultural Systems in Strawberries) was very successful this year. The goal of the project funded by UC-SAREP and USDA/ARS is to work directly with farmers to develop alternative cropping systems for strawberries. The lack of fumigation in this cropping system is one significant factor. The key to the project is the on-farm research. Last year our project worked with 13 growers on 40 acres. We are also working very closely with an industry partner, who is working to have many of the materials being tested, registered by OMRI (Organic Materials Research Institute) for use in organic production.

All of our research is being conducted with farmers in commercial production fields. Most of the fields had been fumigated the previous year and as expected in most plots few differences were seen between non-treated plots and methyl bromide fumigated plots in the first year after fumigation. Treatment differences will increase in subsequent years as strawberries are produced in these fields in the absence of fumigation. However, even under these conditions, in some field trials the biologically integrated system significantly increased yield and control of weeds over the controls.

2) **Enhancement of organic strawberry production.** Our overall goal is to increase the viability of organic strawberry production as an alternative crop production system. In work funded by the USDA/ARS and CA-DPR, we are working to 1) evaluate the performance of commercially available strawberry cultivars under organic strawberry production in California; 2) to evaluate the potential of increasing yield in organic strawberry production by inoculating roots with commercially available vesicular arbuscular mycorrhizae (AM) inoculant at planting; 3) identify isolates of AM from strawberry that are beneficial to strawberry production; 4) identify plant disease problems that are significant in organic strawberry production. These goals are being accomplished through on-farm field trials in cooperation with growers.

This project provides organic farmers and transitional farmers with basic information about the performance of strawberry cultivars produced on organically managed farmers. In the first side-by-side comparisons of commercially available cultivars under organic management, the cultivars Aromas, Pacific, and Seascape were consistently the top performing of those tested. Cultivars Diamante, Douglas, Hecker, Pajaro, Selva, Sequoia, Capitola, Camarosa, Carlsbad, Cartuno, Irvine, and Gaviota were also evaluated. The data indicated that significant differences in yield occur among cultivars grown under organically managed conditions.

A commercially available mycorrhizal inoculant provided no benefit to organic strawberry production. Although transplants were initially sparsely colonized, inoculation with a commercial inoculant did not increase the percent of the roots colonized when plants were grown in organic fields. Likewise there was no increase in yield due to the mycorrhizal inoculant. The failure may be due to the presence of adequate mycorrhizal inoculum in the organic production fields.

3) **Identification of microorganisms that may be involved in the plant growth effect of methyl bromide fumigation or in biological control of soilborne plant pathogens.** Using funding from the USDA/ARS we have identified a novel group of microorganisms which inhibit soilborne plant pathogens. These organisms also interact with bacteria that are used as biological control agents for soilborne plant pathogens. We have identified these organisms from strawberry production fields and are working with other scientists to evaluate the effect of soil fumigation on the presence of these organisms. Additionally we have characterized their populations in organic and conventional production systems. Interactions between this group and other organisms important in strawberry production are currently being evaluated. Our goal is to use these organisms to increase yield and reduce soilborne diseases in strawberry.

Chemical and Cultural Alternatives to Methyl Bromide Fumigation of Soil for Strawberry: Research Progress Report, Spring, 2001

J. M. Duniway, D. M. Dopkins and J. J. Hao
Department of Plant Pathology, University of California, Davis, CA 95616

The experiments reported here are part of a project supported largely by the California Strawberry Commission, UC IPM Project, UC Sustainable Agricultural Research and Education Program, and USDA Cooperative State Research Education & Extension Service to research chemical and nonchemical alternatives to methyl bromide for pre-plant fumigation of soil in strawberry production.

Chemical Alternatives: Chemical alternatives to methyl bromide have been tested in replicated field experiments at the Monterey Bay Academy (MBA) near Watsonville. The effects of a virtually impermeable plastic film (VIF), fumigant applications to beds in water emulsion through drip lines, and lower fumigant rates were tested for 3 years on the same soil containing significant populations of *Verticillium dahliae* and *Phytophthora* spp. (These experiments were done jointly with H. Ajwa, USDA-ARS, Fresno.) Two-row beds were shaped, drip lines installed, and small cloth pouches containing soil with known populations of *V. dahliae* or vermiculite pieces of cultured *Phytophthora cactorum* were buried under plant row locations at depths of 15 and 50 cm. (*Phytophthora* inoculum assays were done by G. T. Browne, USDA-ARS, UC Davis.) Beds were subsequently fumigated and covered with standard black polyethylene mulch or black VIF (Hytibar, Klerk's Plastics). Shank-applied treatments included methyl bromide/chloropicrin (MBC) 67/33 at 325 lb/a, chloropicrin at 200 and 300 lb/a, and Telone C-35 at 283 and 425 lb/a. Treatments applied to beds under plastic in water emulsions through drip lines were chloropicrin at 200 lb/a and Telone C-35 at 283 and 425 lb/a. (Rates are given per unit of treated bed area which was 58% of the total area.) Inoculum pouches were recovered and Selva was transplanted through the plastic mulch one month after fumigation. Conventional practices for annual strawberry production and pest management for the area were followed.

MBC killed all inoculum buried at 15 and 50 cm. With the exception of Telone C-35 at the lower rate, other shank-applied treatments reduced buried *V. dahliae* inoculum to very low or undetectable levels. The same treatments killed most of the *P. cactorum* buried at 15 cm but were only effective in doing so at the 50 cm depth where VIF plastic was used. With the exception of chloropicrin at 200 lb/a, all drip-applied treatments killed both fungi at a depth of 15 cm but not at 50 cm. This survival probably occurred because the volume of water used to deliver fumigants was insufficient for movement to the 50 cm depth. Disease incidence in the growing crop was variable, but both Verticillium wilt and Phytophthora root rot were controlled adequately in most fumigation treatments. All fumigation treatments effectively controlled weed growth through plant holes in the plastic mulch.

Shank fumigation of beds with MBC and VIF mulch more than doubled berry yields relative to nontreated soil, and MBC with standard mulch was only slightly less effective. With standard plastic mulch, chloropicrin at 200 lb/a and Telone C-35 at 283 and 425 lb/a, when shank- or drip-applied, gave yields as high as or higher than those obtained with MBC. Use of VIF plastic mulch, however, increased yields significantly in all chloropicrin treatments and in some Telone C-35 treatments. These results are similar to those obtained in 1997-98 when VIF mulch improved yields significantly in a variety of shank-applied bed fumigation treatments, but differ from those obtained in 1998-99 when VIF effects were small. A repeat experiment is now underway for 2000-2001. The results show that bed fumigations with the materials and methods used can be effective in the presence of significant disease pressures from soilborne pathogens, but the specific methods and rates of application need further research to be optimized.

Cultural Methods for Management of Verticillium Wilt: Five experiments on strawberry rotations with broccoli, Brussels sprouts, and/or rye have been completed on nonfumigated soils. At MBA with high populations of *V. dahliae* present, none of the rotations reduced the incidence of Verticillium wilt in the subsequent strawberry crop significantly, but physical removal of residues from the preceding strawberry crop did reduce disease in some years. One-year rotations out of strawberry, however, increased subsequent berry yields by 18-44% relative to continuous strawberry.

High-nitrogen organic amendments were incorporated into nonfumigated soil several weeks before planting to test their effects on Verticillium wilt. Feather meal applied to beds (4 tons/a of treated area) reduced disease incidence in Camarosa during both 1999 and 2000, while blood meal (4 and 8 tons/a), fish meal (8 tons/a), and compost (8-12 tons/a) reduced disease in only one of the two years. Amendments applied to beds, however, also caused phytotoxicity and, therefore, did not give increases in yield proportional to levels of disease reduction. Broadcast applications of blood or fish meal at 4 tons/a or feather meal at 2 tons/a before bed shaping reduced Verticillium wilt development during 2000 without causing phytotoxicity in the variety Aromas. Although current California strawberry varieties are all susceptible to Verticillium wilt, some (e.g. Camarosa) were significantly more susceptible than others (e.g. Selva, Chandler, Diamante) when compared over several years in naturally infested soil.

Mechanisms of Fumigation Response in Strawberry: We are continuing to research microbiological differences associated with the enhanced growth and productivity of strawberries in fumigated soils where the response is not due to control of known, major pathogens. A number of fungi isolated from roots growing in nonfumigated soils were damaging to strawberry in greenhouse tests. These same fungi were isolated less frequently from roots in fumigated soils. Populations of fluorescent Pseudomonads in soil increased quickly following fumigation and several isolates of *Pseudomonas fluorescens*, *P. putida* and *P. chlororaphis* from strawberry rhizospheres in fumigated soils were beneficial when inoculated to strawberry transplanted into natural soils in the greenhouse. The results suggest that reductions in deleterious fungi and increases in beneficial fluorescent Pseudomonads contribute to the enhanced growth response of strawberry in fumigated soils.

Strawberry plants were inoculated with some of these *Pseudomonas* bacteria prior to transplanting in 1999 and 2000 at MBA, Watsonville, and SCREC, Irvine, to see if they can be beneficial in the field. (SCREC experiments were done jointly with K. D. Larson, UC Davis.) Inoculations of bare-root and plug plants of Camarosa did not increase yield significantly in MBC-treated and nontreated soil at SCREC. Bacterial inoculations of bare-root Selva also did not increase yield in MBC-treated soil at MBA, and some actually decreased yield significantly. While only one isolate increased yield in nontreated soil, three isolates increased yields significantly in soil treated with 200 lb/a chloropicrin at MBA. Periodic inoculations during crop growth did not increase growth or yields over those obtained following one inoculation at transplanting. These experiments are currently being repeated with modifications in the 2000-2001 crop cycle.

Nursery Experiments: Jointly with others from the Strawberry Commission, UC Davis, and USDA-ARS, and with the help of individual strawberry nurseries and growers, we are researching the possible use of Iodomethane (methyl iodide) and Telone with chloropicrin as preplant fumigants for high- and low-elevation production of runner plants. This project started spring, 2000, and runners from these experiments are being evaluated for their subsequent performance in runner and berry production.

Management of Root Diseases of Strawberry

Frank N. Martin, USDA-ARS, 1636 East Alisal St., Salinas, CA 93905

Historically one of the primary reasons for soil fumigation was to reduce the incidence of Verticillium wilt, the most important lethal disease of strawberry. However, a number of other nonlethal soilborne fungal pathogens also can contribute to significant losses when strawberry is grown in nonfumigated fields. In one of the PI's field plots that did not have Verticillium wilt there was a 46% reduction in marketable yield in 1998 when the strawberry cultivar Selva was grown in nonfumigated soil; based on root isolations this yield decline was attributed to root rot caused by *Pythium*, binucleate *Rhizoctonia*, and *Cylindrocarpon* spp. Collectively these general, nonspecific pathogens cause a root disease commonly referred to as black root rot. In view of the high level of recovery of these pathogens from the roots the first 4-5 months after transplanting it is suspected that they contribute to the significant reductions in plant growth observed when strawberry is grown in nonfumigated soil. This translates into a smaller, less thrifty plant in the early spring that is not able to support the fruiting level that is expected for plants in an economically viable production field. Attempts to control of these pathogens is being approached from several directions:

Host Tolerance - One approach for mitigating the loss of methyl bromide soil fumigation for disease control would be to plant strawberry cultivars that are tolerant to specific root pathogens. Screening programs are currently underway in other laboratories in California evaluating tolerance to Verticillium wilt and Phytophthora root and crown rot. These are two important diseases of strawberry that can cause significant crop losses by reducing yield as well as killing the plant. The efforts of the PI's research program have focused on determining the contribution of the individual pathogens associated with black root rot on the severity of the disease complex in the field as well as evaluating host germplasm for pathogen tolerance in the greenhouse and field.

Greenhouse trials

Greenhouse evaluations for tolerance to *Pythium ultimum* and different anastomosis groups (AGs) of binucleate *Rhizoctonia* (a mixture of isolates in AG-A, –G, and -I) revealed different levels of tolerance to these pathogens among the various cultivars. In evaluations with *P. ultimum* at 200 p/g soil, Selva, Aromas and Carlsbad exhibited lower levels of inhibition of root or shoot growth whereas Camarosa and Chandler exhibited significant reductions in shoot and root growth. Similar results also were observed for Seascape (tolerant), Torrey and Pajaro (susceptible). The presence of binucleate *Rhizoctonia* caused significant reductions in shoot growth for all cultivars examined; similar results were observed for root weights as well.

Filed Evaluations

Field trials to evaluate cultivar performance in nonfumigated soil have been conducted in test plots in Salinas. The location has not been previously fumigated and is naturally infested with the pathogens associated with black root rot. Importantly, Verticillium wilt and Phytophthora root and crown rot have not been a problem at this test location, so trials evaluating the contribution of the general root pathogens associated with black root rot on plant growth and yield can be conducted independent of these lethal pathogens. There were dramatic differences in growth and yield performance among the cultivars. With the exception of Laguna, all cultivars exhibited significant reductions in plant diameter measurements when grown in nonfumigated soil compared to the MB + Pic fumigated control in 1999. The greatest reduction in growth was observed for Oso Grande, which had approximately a 50% reduction in plant diameter. In general, there was less of a reduction in plant diameter measurements for the 2000 season, however, Camarosa, Chandler, Diamante, Oso Grande, Pacific, and Pajaro all exhibited significant reductions when grown in nonfumigated soil. A wide range in yield also was observed among cultivars. For example, there was no difference in total yield for Capitola grown in nonfumigated compared to the fumigated control in 1999; in contrast Oso Grande exhibited approximately a 70% reduction in yield when grown in nonfumigated soil. With a few exceptions, yield in nonfumigated relative to yield in fumigated soil was similar for both seasons. While the yield in nonfumigated soil was proportional to the yield in fumigated soil for some cultivars, this was not observed for all comparisons. For example, total yield in fumigated soil for Gaviota, Irvine, Laguna, and Oso Grande were similar, however, in nonfumigated soil Oso Grande has dramatically lower yields than the other cultivars.

Crop rotation - A number of strawberry root pathogens have a broad host range and are capable of infecting other crops, so in the absence of effective soil fumigation crop rotation can have a significant influence on maintaining populations of soilborne pathogens. Field trials in collaboration with Krishna Subbarao (UC Davis) and Steve Koike (UC Cooperative Extension) evaluating the influence of rotation with broccoli, Brussels sprouts, or lettuce on the population dynamics of *Pythium* spp. and *Verticillium dahliae* are in progress at the Watsonville test site. The field was cropped in vegetable rotation in the 1997 season, strawberry (Selva) in the 1998 season, vegetable rotation in 1999 and was in strawberry in 2000. After harvesting the vegetable crops, the stubble was mowed with a flail mower, allowed to dry on the soil surface for several days and then incorporated into the soil. Two cropping cycles were planted for broccoli and lettuce and one for Brussels sprouts. While cropping practices had no consistent influence of population densities of total *Pythium* spp., broccoli and Brussels sprouts reduced *V. dahliae* inoculum densities by 80-90% (to a final inoculum density of 1-2 microsclerotia/g soil). Although the market yield for all rotation treatments was below the MB + Pic fumigated controls in 1998, strawberry grown in the broccoli rotation plots had only a 23% reduction in yield compared to the fumigated control while Brussels sprouts and lettuce had yield reductions of 31% and 39%, respectively. These trials have been expanded at the Watsonville test site to include larger test areas as well as the addition of a test plot in an organic production field. Similar experiments (rotation with broccoli, cauliflower, or lettuce) also are underway at the Salinas plots as well to evaluate the effect of rotation crops on the population dynamics of root rotting pathogens.

The influence of root colonizers of root health, plant growth, and yield - Preliminary investigations on the population structure and seasonal fluctuations of fungal, bacterial, and actinomycete root colonizers have been done for plants grown in fumigated and nonfumigated soils. Field trials were conducted with several isolates that were found to be beneficial in growth chamber trials. In 1998, trials at the USDA test site in Salinas in nonfumigated soil identified several isolates that significantly increased yield over the untreated control plants when plants were treated at the time of transplanting (one isolate gave a 35.5% increase in marketable yield). However, trials in the 1999 season did not reveal significant differences among the treatments. One possible reason for this could be that there was much less rainfall in 1999 compared to 1998 (31 vs 74 cm, respectively). Since soil moisture can have a significant effect on the ability of introduced microbial inoculants to colonize roots, the drier conditions in 1999 could have lead to lower root colonization levels which in turn would lead to a reduced effect on strawberry yield. To alleviate potential problems with insufficient root colonization, trials were conducted last season with several of these isolates where additional treatments with the microbial inoculants are applied via the drip system. Trials evaluating the efficacy of several commercial biological control agents are underway as well.

Fumigation trials - Fumigation trials have been done in collaboration with Husein Ajwa to evaluate the efficacy of alternative fumigants and methods for application for their ability to control *Pythium ultimum*, the most commonly recovered *Pythium* spp. from strawberry in the central coastal production area of California. Naturally infested soil was placed into nylon mesh bags and buried at two depths 8 cm from the center of the strawberry beds. The bags were recovered 6.5 wks after fumigation and the pathogen populations determined by plating on a selective medium. All fumigation treatments (methyl bromide + Pic, Iodomethane, propargyl bromide, Pic) completely eliminated *P. ultimum* with the exception of the Telone C-35 treatments at the 16-inch depth (20% and 10% survival for the drip and shank treatment, respectively). Buried bag inoculum also was placed in fumigation trials done at high and low elevation nursery sites conducted by a consortium of California Strawberry Commission, UC and USDA researchers (samples were part of the *Verticillium dahliae* inoculum placed in the field by John Duniway). In both trials iodomethane provided excellent control of *P. ultimum* to a depth of 60 inches.

March 2002

Management of Root Diseases of Strawberry

Frank N. Martin, USDA-ARS, 1636 East Alisal St., Salinas, CA 93905

A number of other nonlethal soilborne fungal pathogens can contribute to significant losses when strawberry plants are grown in nonfumigated fields. Based on root isolations from our plots in Watsonville and Salinas area this reduction in yield was attributed to root rot caused by *Pythium*, binucleate *Rhizoctonia*, and *Cylindrocarpon* spp. Collectively these general, nonspecific pathogens cause a root disease commonly referred to as black root rot. In view of the high level of recovery of these pathogens from the roots the first 4-5 months after transplanting it is suspected that they contribute to the significant reductions in plant growth observed when strawberry is grown in nonfumigated soil. This translates into a smaller, less thrifty plant in the early spring that is not able to support the fruiting level that is expected for plants in an economically viable production field. Research is in progress to evaluate the distribution of these pathogens in the California production area and to assess if there are seasonal differences in their recovery from plants. Attempts to control of these pathogens is being approached from several directions:

Host Tolerance

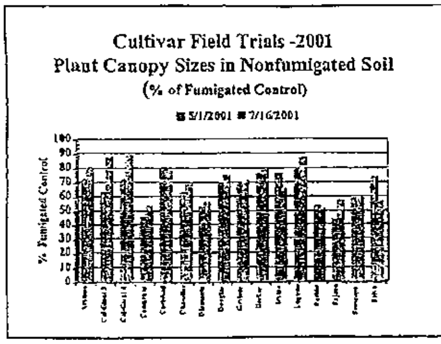
One approach for mitigating the loss of methyl bromide soil fumigation for disease control would be to plant strawberry cultivars that are tolerant to specific root pathogens. One of the objectives of our research program is to determine the contribution of the individual pathogens associated with black root rot on the severity of the disease complex in the field as well as evaluating host germplasm for pathogen tolerance in the greenhouse and field.

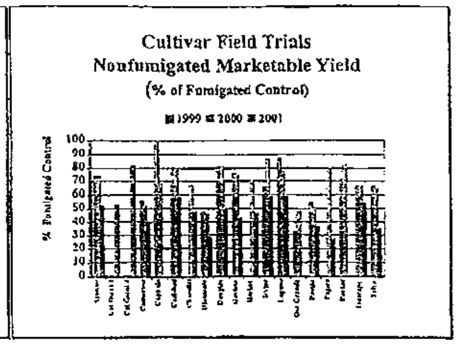
Greenhouse trials

Tests to evaluate the susceptibility of specific cultivars to black root rot pathogens have been conducted in the greenhouse under controlled conditions. Definite differences in the level of root rot and reduction in shoot growth have been observed among the cultivars. For example, Selva, Seascape, Aromas and Carlsbad were much less sensitive to *P. ultimum* than were Camarosa and Chandler. Similar evaluations are in progress with different isolates of binucleate *Rhizoctonia* as well. Trials to evaluate the influence of these pathogens on different cultivars also are in progress in the field by adding pathogen inoculum to fumigated soil prior to transplanting.

Field Evaluations

Field trials to evaluate cultivar performance in nonfumigated soil have been conducted in test plots in Salinas. The location has not been previously fumigated and is naturally infested with the pathogens associated with black root rot. Importantly, Verticillium wilt and Phytophthora root and crown rot have not been a problem at this test location, so trials evaluating the contribution of the general root pathogens associated with black root rot on plant growth and yield can be conducted independent of these lethal pathogens. Plants grown in nonfumigated soil were smaller than those in MB + Pic fumigated soil; the extent of this inhibition of growth was quantified by analysis of digital images. There was a good correlation between the level of growth inhibition measured by canopy coverage and subsequent yield ($r^2 = 0.79$); the greater the stunting the lower the yield. The yield results from these trials were fairly consistent for the first two years the trials were conducted. While general trends in susceptibility were consistent in the third year, due to the high pathogen pressure the yields were less that previously obtained. Trials are in progress this season with newer UC cultivars and proprietary cultivars from a private company.



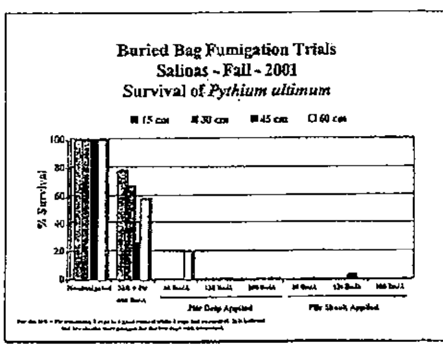


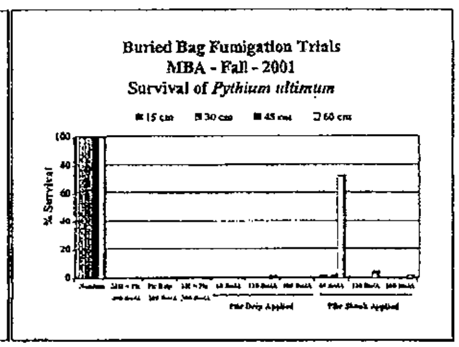
Crop rotation

A number of strawberry root pathogens have a broad host range and are capable of infecting other crops, so in the absence of effective soil fumigation crop rotation can have a significant influence on maintaining populations of soilborne pathogens. Field trials in collaboration with Krishna Subbarao (UC Davis) and Steve Koike (UC Cooperative Extension) evaluating the influence of rotation with broccoli, Brussels sprouts, or lettuce on the population dynamics of *Pythium* spp. and *Verticillium dahliae* are in progress at the Watsonville test site (8/28/01 Pink Sheet). These trials were expanded at the Watsonville test site last year to include larger test areas as well as the addition of a test plot in an organic production field. Similar experiments (rotation with broccoli, cauliflower, or lettuce) also are underway at the Salinas plots as well to evaluate the effect of rotation crops on the population dynamics of root rotting pathogens.

Fumigation trials

Fumigation trials have been done in collaboration with 7 other USDA-ARS and UC scientists to evaluate the efficacy of alternative fumigants and methods for application for control of soilborne pests. Our work has focused on *Pythium ultimum*, the most commonly recovered *Pythium* spp. from strawberry in the central coastal production area of California. Trials have been conducted with a variety of fumigants, including Telone C-35, Inline, Chloropicrin, and Iodomethane. Trials also were conducted with propargyl bromide, a nonregistered fumigant with excellent efficacy.





Chemical and Cultural Alternatives to Methyl Bromide Fumigation of Soil for Strawberry: Research Progress Report, Spring, 2002

J. M. Duniway, D. M. Dopkins and J. J. Hao
Department of Plant Pathology, University of California, Davis, CA

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Chemical Alternatives for Berry Production: Chemical alternatives to methyl bromide have been tested in replicated field experiments at the Monterey Bay Academy (MBA) near Watsonville. The effects of a virtually impermeable plastic film (VIF), fumigant applications to beds in water emulsion through drip lines, and lower fumigant rates were tested for 4 years on the same soil containing significant populations of *Verticillium dahliae* and *Phytophthora* spp. (These experiments were done jointly with H. Ajwa, USDA-ARS, Fresno.) Two-row beds were shaped, drip lines installed, and small cloth pouches containing soil with known populations of *V. dahliae* or vermiculite pieces of cultured *Phytophthora cactorum* were buried under plant row locations at depths of 15 to 60 cm. (*Phytophthora* inoculum assays were done by G. T. Browne, USDA-ARS, UC Davis.) Beds were subsequently fumigated and covered with standard black polyethylene mulch or black VIF (Hytibar, Klerk=s Plastics). Shank-applied treatments included methyl bromide/chloropicrin (MBC) 67/33 at 325 lb/a, chloropicrin at 200 and 300 lb/a, and Telone C35 at 283 and 425 lb/a. Treatments applied to beds under plastic in water emulsions through drip lines were chloropicrin at 200 lb/a and InLine (Telone C35) at 283 and 425 lb/a. (Rates are given per unit of treated bed area which was 58% of the total area.) Inoculum pouches were recovered and Selva was transplanted through the plastic mulch one month after fumigation. Conventional practices for annual strawberry production and pest management for the area were followed.

Unlike the previous years when much higher levels of control were achieved, none of the fumigation treatments was fully effective in controlling buried inoculum of *V. dahliae* or *P. cactorum*. Although the results were variable, the use of VIF plastic as compared to standard plastic improved pathogen and disease control in some treatments. All fumigation treatments effectively controlled weed growth through plant holes in the plastic mulch.

Fumigation treatment effects on yields in 2001 were also variable. For example, with standard plastic, only MBC and shank applied Telone C35 at 425 lb/a increased yield significantly; with the VIF plastic, Telone C35 shank applied at 283 lb/a and InLine at 425 lb/a also increased yield. When all chemical treatments are considered, use of VIF plastic increased yield by an average of 30%. This VIF effect is similar to those obtained in 1997-98 and 1999-2000 when VIF mulch improved yields significantly in a variety of bed fumigation treatments, but differ from those obtained in 1998-99 when VIF effects were small. The results suggest that the use of VIF plastic rather than standard plastic is more likely to be beneficial under marginal conditions for soil fumigation and/or with lower rates of fumigants.

Chemical Alternatives for Nursery Plant Production: Jointly with others from the Strawberry Commission, UC Davis, and USDA-ARS, and with the help of individual strawberry nurseries and growers, we are researching the possible use of Iodomethane (methyl iodide, MeI), Telone C35, chloropicrin, and Basamid as preplant fumigants for high- and low-elevation nursery production of runner plants. This project started spring, 2000, and runners from these experiments are being evaluated for their subsequent performance in runner and berry production.

Although runner plant production was reduced significantly on nonfumigated soils at both low- and high-elevations, transplants from non-fumigated soil and soil treated with MBC or MeI/chloropicrin at high elevation gave equivalent berry yields on fumigated soil in Watsonville. There was, however, a negative carryover effect of non-fumigated soil at low elevation on subsequent runner production at high elevation. MBC, MeI/chloropicrin, chloropicrin alone, and Telone C35, the latter two followed by Basamid (see rates given below), gave similar numbers of runners at high elevation. Sub-samples of these were transplanted into fields in Oxnard and Watsonville in the fall of 2001 for further evaluation.

Fumigant Control of Verticillium in Soil: As part of the cooperative project above, the effectiveness of various fumigation treatments at controlling inoculum of *V. dahliae* buried at several depths in field soil was examined. In shank applied nursery fumigations, a 50/50 mixture of MeI and chloropicrin (350 lb/a) was as effective as the standard MBC at depths of 15, 30, 60 and 90 cm; chloropicrin (250 lb/a) and Telone C35 (360 lb/a) followed by Basamid (250 lb/a) were also effective at 15 and 30 cm, but were less effective at depths of 60 and 90 cm. In berry production beds, drip applied chloropicrin (300 lb/a), InLine (400 lb/a), and MeI/chloropicrin (400 lb/a) were nearly as effective as the standard MBC at depths of 15 and 30 cm, but were sometimes less effective at 45 and 60 cm. Drip applied propargyl bromide (180 lb/a) generally gave the most complete control of *V. dahliae* at all depths tested.

Inoculations with Beneficial Root-Colonizing Bacteria: We are continuing to isolate bacteria from strawberry rhizospheres in fumigated soils that are beneficial when inoculated to strawberry transplanted into natural soils in the greenhouse. Bare-root runner plants were inoculated with some of these bacteria in the fall of 2000 and transplanted into field plots treated with MBC, chloropicrin (200 lb/a), or not treated. All of the inoculations in MBC-treated soil decreased yield. While only one isolate increased yield in chloropicrin-treated soil, three isolates did so in non-treated soil, and two reduced the incidence of Verticillium wilt. Periodic reinoculations during crop growth did not increase growth or yields over those obtained following one inoculation at transplanting. These experiments are currently being repeated with modifications in the 2001-2002 crop cycle at MBA, Watsonville, and SCREC, Irvine (SCREC experiment done jointly with K. D. Larson, UC Davis).

Cultural Methods for Management of Verticillium Wilt: Cultural methods for the management of Verticillium wilt in strawberry are also under investigation. In previous experiments, high-nitrogen organic amendments incorporated into non-fumigated soil several weeks before planting reduced the incidence of Verticillium wilt. In the 2000-2001 season, however, neither blood, fish, nor feather meal applied to beds at 2-8 tons/a of treated area reduced Verticillium wilt significantly in the susceptible cultivar Camarosa in an experiment where disease pressure was high. Nevertheless, some of the amendments did increase berry yield. Repeated broadcast applications (i.e., ground treated once in 1999 and 2000) of blood or fish meal at 4 tons/a or feather meal at 3 tons/a before bed shaping reduced Verticillium wilt development during 2000-2001 without causing phytotoxicity in the less susceptible variety Aromas. Although current California strawberry varieties are all susceptible to Verticillium wilt, some (e.g. Camarosa) were significantly more susceptible and have a lower inoculum threshold for disease than others (e.g. Selva).

Appendix D.

List of Technical Reports and Presentations Resulting from Project

Publications and Presentations

Publications

Martin, F. N. and Bull, C. T. 2001. Biological approaches for control of root diseases in strawberry. Phytopathology 91: In review.

Johnson, Mark. Dissertation in preparation on colored tarps.

California Strawberry Commission Pink Sheets

01-11, Issued August 28, 2001

<u>Crop Rotation with Broccoli for Management of Verticillium Wilt</u>
Krishna V. Subbarao[1], Frank Martin[2], and Steve Koike[3]
[1]UC Davis, Plant Path. Dept., Salinas; [2]USDA-ARS, Salinas and [3]UC Cooperative Extension, Mo. Co. County,

02-09, Issued March 19, 2002

<u>Strategies for Management of *Phytophthora* on California Strawberries</u>
G.T. Browne, H.E. Becherer, S.T. McLaughlin, and R.J. Wakeman
USDA-ARS, Department of Plant Pathology UC Davis

Methyl Bromide Alternatives Outreach Presentations – 2001 Conference

<u>OUTLOOK FOR MANAGING PHYTOPHTHORA DISEASES ON CALIFORNIA STRAWBERRIES WITHOUT METHYL BROMIDE</u>
*G.T. Browne[1], H.E. Becherer[1], M.R. Vazquez[1], S.A. McGlaughlin[1], R.J. Wakeman[1], C.Q. Winterbottom[2], J.M. Duniway[3], and S.A. Fennimore[4].
[1]USDA-ARS, Dept. of Plant Pathology, UC Davis; [2]Sunrise Farms, Watsonville, CA; [3]Dept. of Plant Pathology and [4]Dept. of Vegetable Crops, [3,4]UC Davis.

<u>CHEMICAL, CULTURAL, AND BIOLOGICAL ALTERNATIVES TO METHYL BROMIDE FOR STRAWBERRY</u>
J. M. Duniway[a]*, J. J. Hao[a], D. M. Dopkins[a], H. Ajwa[b], and G. T. Browne[c]
[a]Department of Plant Pathology, University of California, Davis, CA 95616
[b]USDA-ARS, Water Management Research Laboratory, Fresno, CA 93727
[c]USDA-ARS, Dept. of Plant Pathology, University of California, Davis, CA 95616

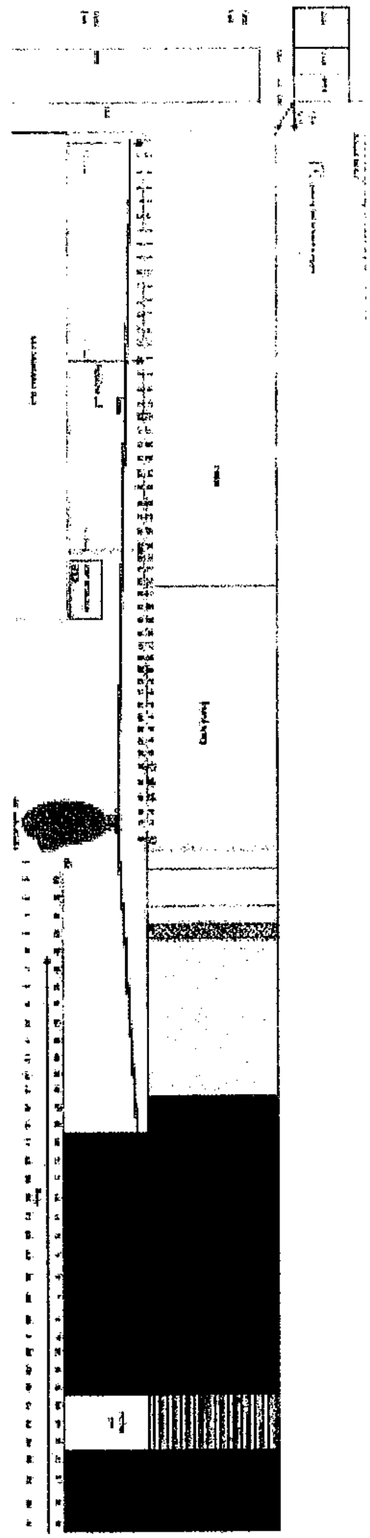
MANAGEMENT OF PATHOGENS ASSOCIATED WITH BLACK ROOT ROT OF STRAWBERRY

Frank N. Martin, USDA-ARS, 1636 East Alisal, Salinas, CA 93905

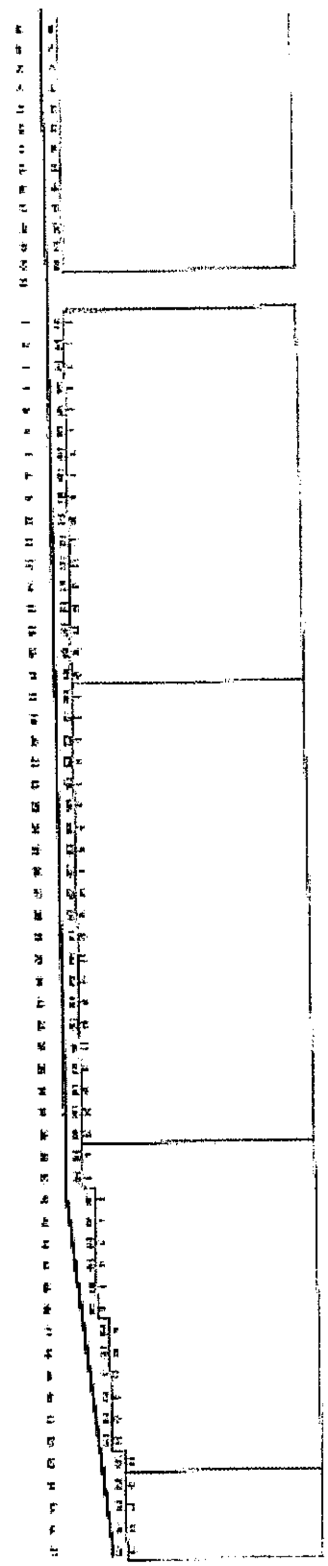
Appendix E.

Site Maps

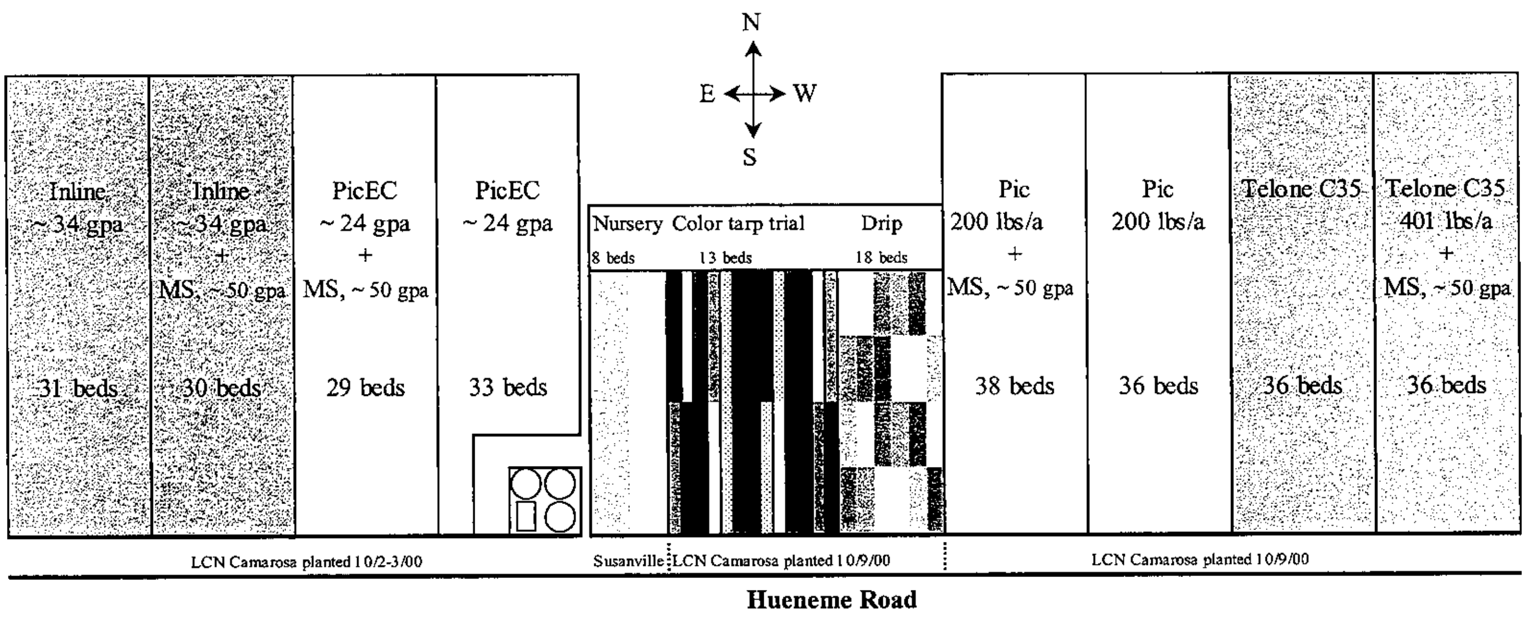
Monterey Bay Academy



Monterey Bay Academy



California Strawberry Commission
Methyl Bromide Alternatives Trials 2000-2001
Location: Martinez Berry Farm, Oxnard, California



MBA Organic Plot 2000-2001
Mycorrhizae Innoculant Trial
Adria Bordas and Carolee Bull

Yield	20 plants	Cultivar Used: Aromas
Colonization	12 plants	
Total	32 plants per plot	

plot ft	bed feet	1	2	3	4	5	6	7
5	80							
16	75	904 7	908 6	912 5	916 4	920 2	924 3	928 1
2	59							
16	57	903 4	907 6	911 1	915 5	919 7	923 3	927 2
2	41							
16	39	902 2	906 7	910 6	914 3	918 4	922 1	926 5
2	23							
16	21	901 7	905 1	909 2	913 3	917 5	921 4	925 6
5	5	CTB1	CTB2	CTB3	CTB4	CTB5	CTB6	CTB7

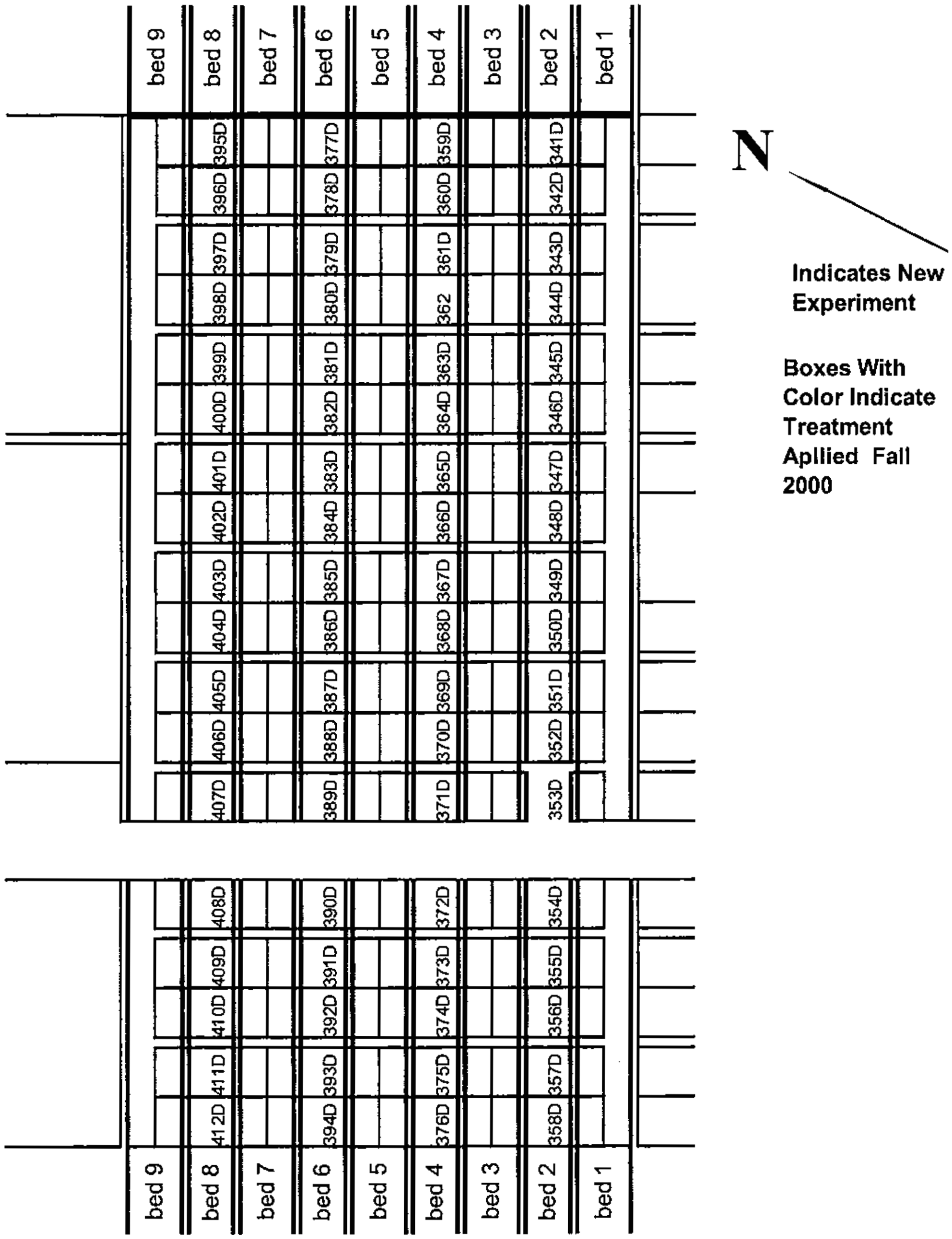
Key: #901-928 = plot number
#1-7 = treatment number

2000-2001

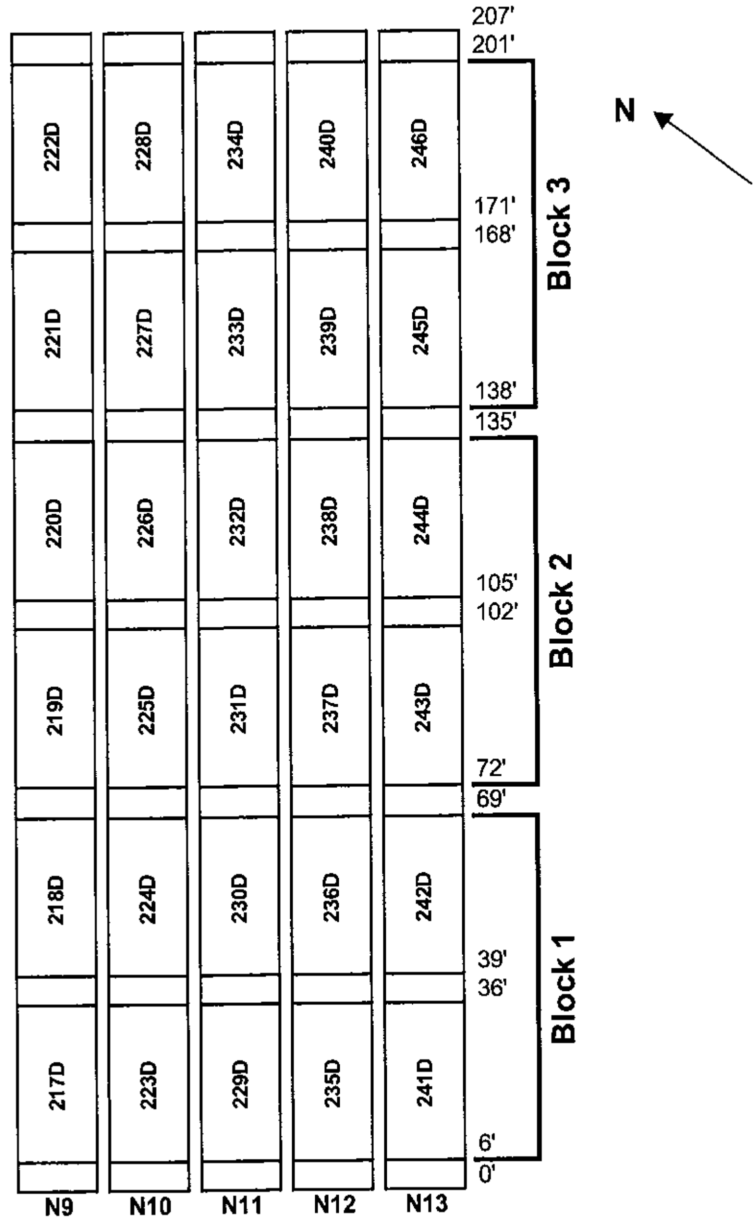
Bacterial Inoculation at MBA

74D	75D	76D	77D	78D	79D	80D	81D	82D	83D	84D
86D	87D	88D	89D	90D	91D	92D	93D	94D	95D	96D
98D	99D	100D	101D	102D	103D	104D	105D	106D	107D	108D
110D	111D	112D	113D	114D	115D	116D	117D	118D	119D	120D
122D	123D	124D	125D	126D	127D	128D	129D	130D	131D	132D
134D	135D	136D	137D	138D	139D	140D	141D	142D	143D	144D

2000-2001 Coastal Organic Amendment Experiment

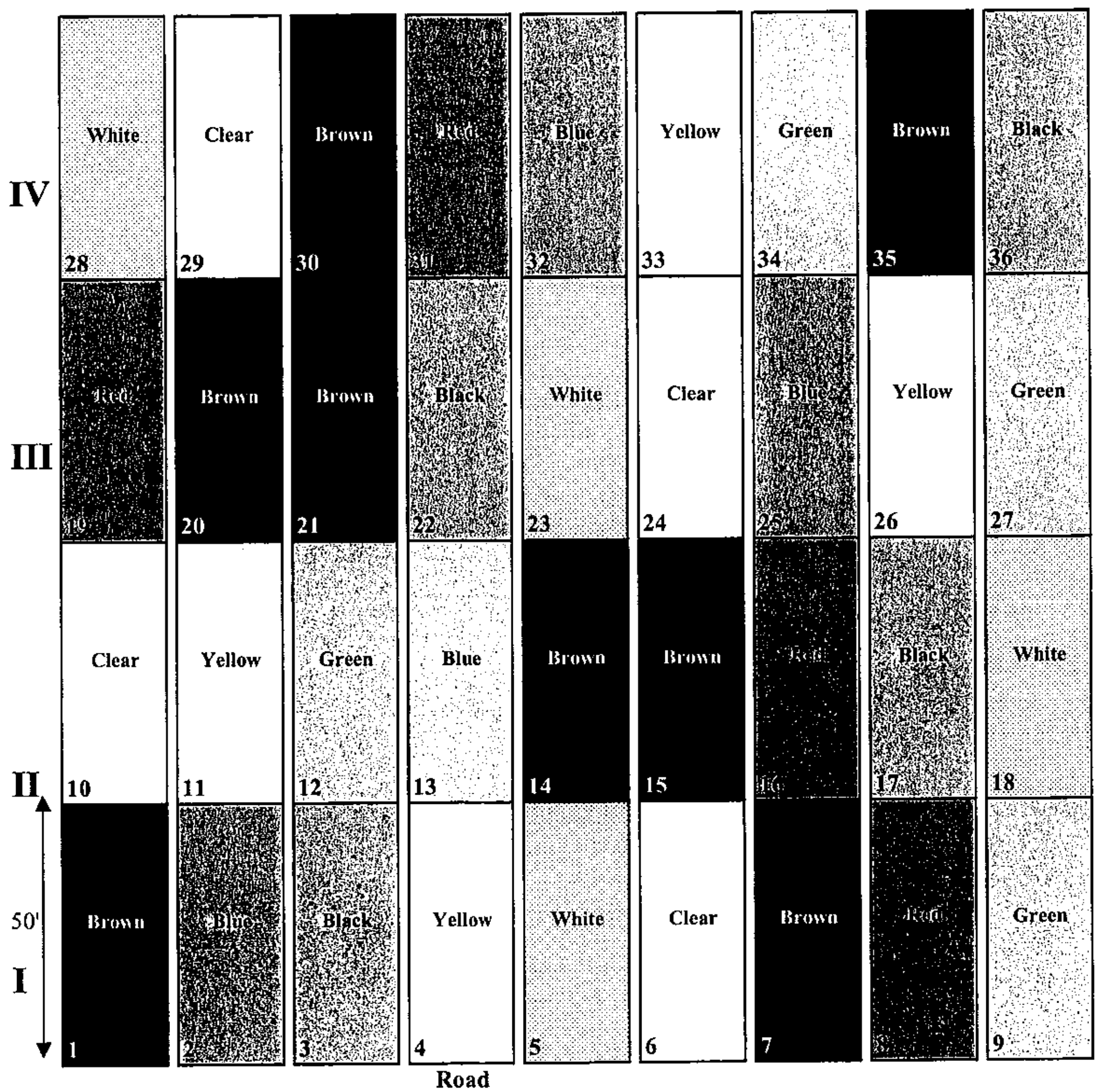


MBA Organic Amendment 2000-2001



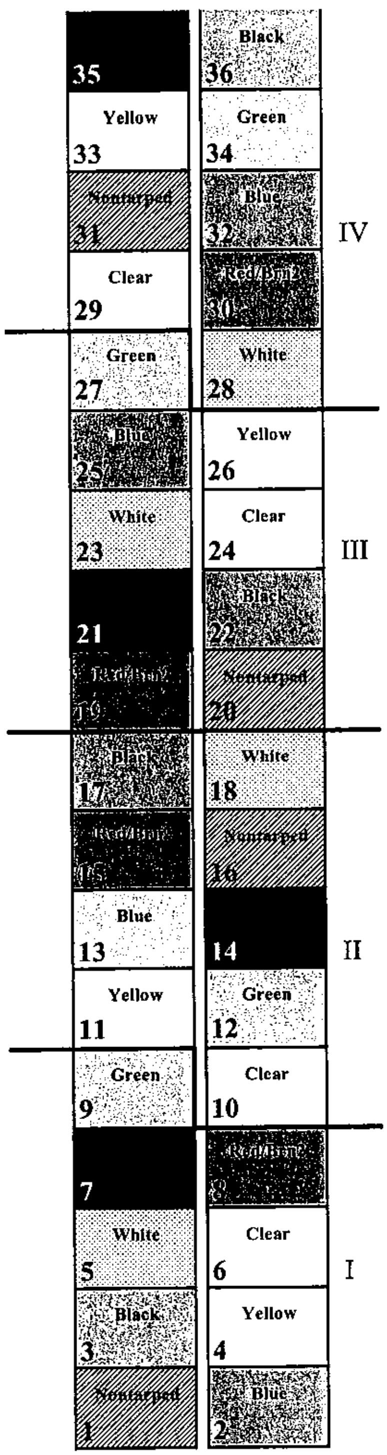
California Strawberry Commission, USDA/ARS, CSREES
Methyl Bromide Alternatives Trials 2000-2001

Location: Watsonville, California
Cooperator(s): Coastal Berry, LLC



California Strawberry Commission, PMA
Methyl Bromide Alternatives Trials 2000-2001
Color Tarp Trial in Organic Production

Location: Watsonville, California
Cooperator(s): Coastal Berry, LLC



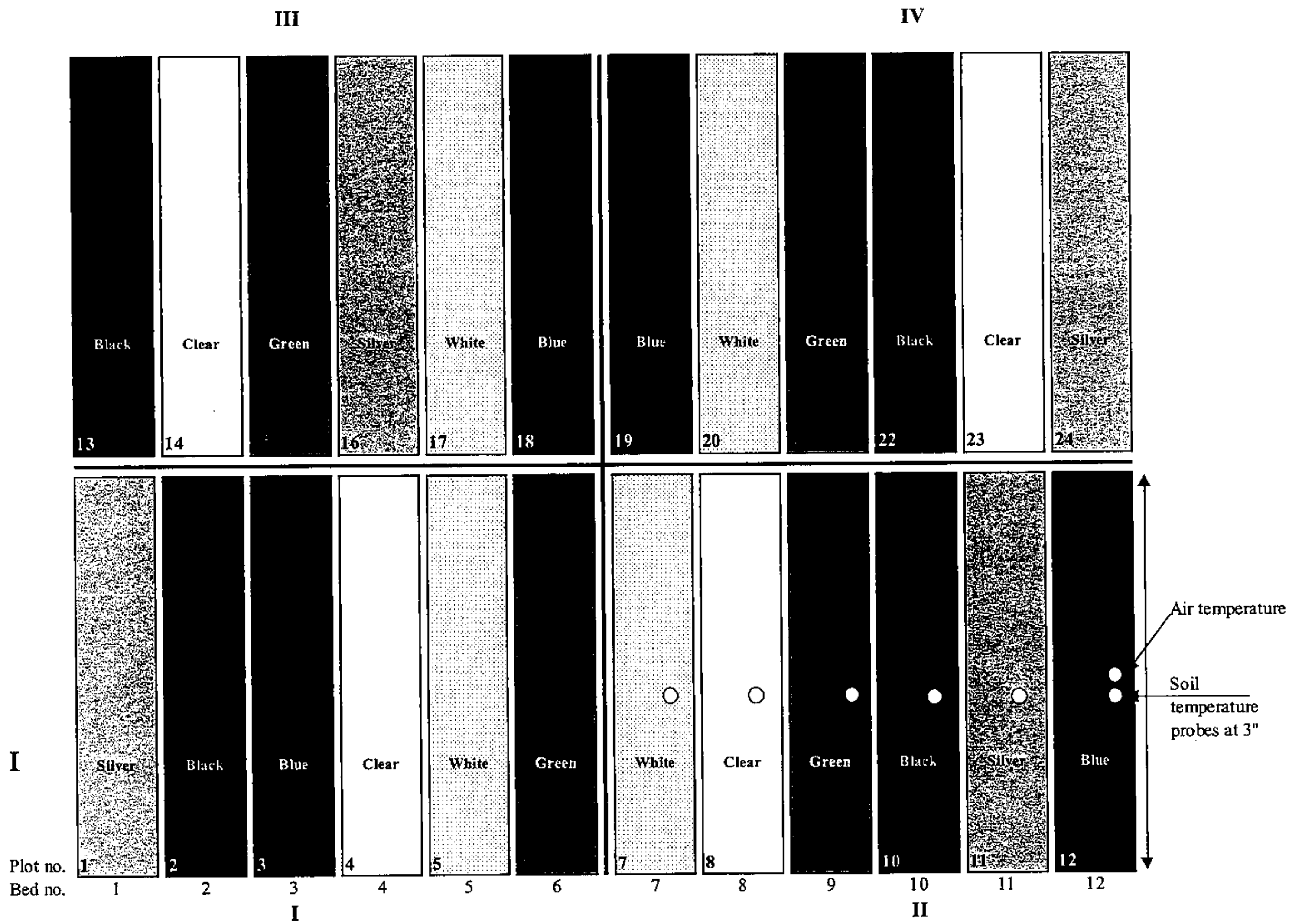
California Strawberry Commission, USDA/ARS, CSREES
Methyl Bromide Alternatives Trials 2000-2001

Location: Oxnard, California

Cooperator(s): Cecil Martinez, Martinez Farms

Cultivar: Camarosa (from Mcdoel), plantedl 0/9/00

Bed fumigated on 8/25/00 with chloropicrin, planted with Mcdoel Camarosa 10/9/00
Used 131 lbs of chloropicrin in 12 beds of 335' (64" c to c, ave bed width is 45")
Rate = 187 lbs/ treated acre



MBA 2000-2001, Verticillium ID-DI

Pick Map

North ↑ → East

5' 22' 24' 41' 43' 60' 66' 72' 89' 91' 108' 110' 127' 133' 139' 156' 158' 175' 177' 194'

	Block 1			Block 2			Block 3		
N1	145D	146D	147D	148D	149D	150D	151D	152D	153D
N2	154D	155D	156D	157D	158D	159D	160D	161D	162D
N3	163D	164D	165D	166D	167D	168D	169D	170D	171D
N4	172D	173D	174D	175D	176D	177D	178D	179D	180D
N5	181D	182D	183D	184D	185D	186D	187D	188D	189D
N6	190D	191D	192D	193D	194D	195D	196D	197D	198D
N7	199D	200D	201D	202D	203D	204D	205D	206D	207D
N8	208D	209D	210D	211D	212D	213D	214D	215D	216D

22 Dia fra	52 Honeye ck	82 Dia cac	112 Cam cac	142 Paj cac	172 Pac cac
21 Hood ck	51 Gav fra	81 Aro cac	111 Cam ck	141 Aro fra	171 Park fra
20 Honeye cac	50 Pac fra	80 Gav ck	110 Hood cac	140 Cam fra	170 Honeye fra
19 Jewel ck	49 Earli ck	79 Pac ck	109 Earli cac	139 Jewel cac	169 Aro ck
18 Park cac	48 Earli fra	78 Jewel fra	108 Park ck	138 Paj fra	168 Dia ck
17 Dia fra	47 Cam fra	77 Jewel fra	107 Hood fra	137 Gav cac	167 Paj ck
16 Park cac	46 Paj cac	76 Cam ck	106 Dia ck	136 Park fra	166 Aro fra
15 Aro ck	45 Paj fra	75 Pac fra	105 Jewel ck	135 Gav fra	165 Aro cac
14 Dia cac	44 Pac cac	74 Earli cac	104 Hood cac	134 Earli ck	164 Gav ck
13 Hood ck	43 Honeye fra	73 Honoye ck	103 Paj ck	133 Jewel cac	163 Earli fra
12 Cam cac	42 Honeye cac	72 Hood fra	102 Park ck	132 Gav cac	162 Pac ck
11 Jewel ck	41 Cam cac	71 Earli fra	101 Pac ck	131 Park fra	161 Pac cac
10 Dia ck	40 Paj ck	70 Aro fra	100 Hood fra	130 Honoye fra	160 Dia cac
9 Pac fra	39 Earli cac	69 Gav ck	99 Cam fra	129 Hood ck	159 Park cac
8 Gav fra	38 Honeye ck	68 Jewel fra	98 Park ck	128 Aro ck	158 Gav cac
7 Honeye cac	37 Dia fra	67 Earli ck	97 Jewel cac	127 Paj fra	157 Aro cac
6 Honeye ck	36 Aro fra	66 Paj fra	96 Hood cac	126 Paj cac	156 Cam ck
5 Cam fra	35 Pac fra	65 Jewel cac	95 Hood cac	125 Hood ck	155 Earli cac
4 Earli fra	34 Gav fra	64 Hood fra	94 Pac ck	124 Aro cac	154 Dia ck
3 Aro ck	33 Park ck	63 Cam cac	93 Paj ck	123 Earli ck	153 Park cac
2 Gav ck	32 Pac cac	62 Jewel fra	92 Dia cac	122 Park fra	152 Cam ck
1 Honeye fra	31 Paj cac	61 Gav cac	91 Honeye cac	121 Jewel ck	151 Dia fra

198 aro cac
197 dia cac
196 aro ck
195 dia ck
194 aro ck
193 dia ck
192 aro cac
191 dia cac
190 skip 2, # cac aro # cac dia
189 skip 2, # ck dia # ck aro
188 skip 2, # ck dia # ck aro
187 skip 2, # cac aro # cac dia
186 skip 2, # cac dia # cac aro
185 skip 2, # ck aro # ck dia
184 skip 2, # cac aro # cac dia
183 skip 2, # ck dia # ck aro
182 skip 2, # cac aro # cac dia
181 skip 2, # ck aro # ck dia

Cultivar Resistance Experiment

Plot number on top

Aro: Aromas
Cam: Camarosa (10/25 fr hi elev)
Dia: Diamante
Ear: Earlimart
Gav: Gaviota
Hon: Honeye
Hoo: Hood
Jew: Jewel
Pac: Pacific
Paj: Pajaro
Par: Parker

Ck: No Phytophthora
cac: soil infested P. cactorum
fra:

Phytophthora Tolerance Experiment